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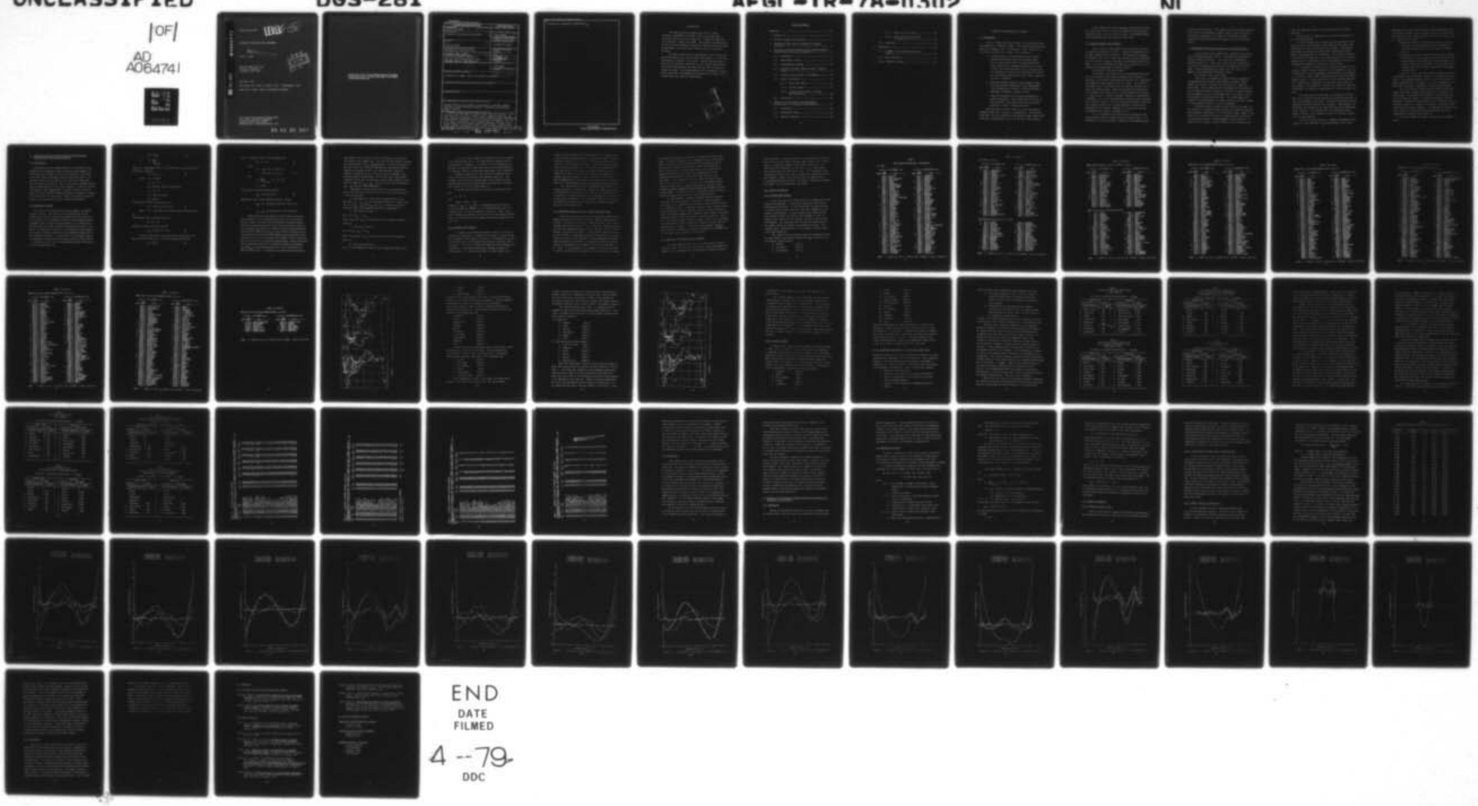

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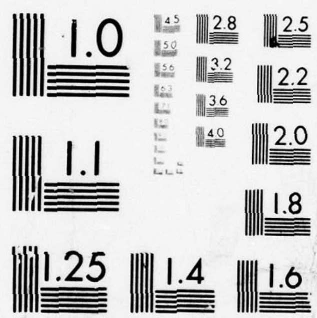

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STUDIES IN GRAVIMETRIC GEODESY

Urho A. Uotila

The Ohio State University
Research Foundation
Columbus, Ohio 43212

December 1978

Final Report for Period 1 January, 1977 - 30 September, 1978

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AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a final report on research done under the contract. Brief mention is made of the two scientific reports submitted under the contract: "Recent Development in the Geodetic Boundary Value Problem" and "Non-Stationary Estimation in Gravity Prediction Problems". The rest of the report concentrates on two technical subjects: Selection of preferred locations of new absolute gravity measurements in gravity basestation networks and analyses on the location of absolute gravity meas- → next page

urements for calibration of gravimeters.

FOREWORD

This final report was prepared by Urho A. Uotila, Professor, Department of Geodetic Science at the Ohio State University under Air Force Contract No. F19628-77-C-0082 OSU RF Project No. 710533 and 710534. This contract is administered by the Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts, with Bela Szabo, Contract Monitor and Project Scientist.

The author expresses his deep gratitude to all of those who have participated in the research under this Contract. A list of the participants is attached to this report. Special mention should be given for the excellent contributions of Drs. Moritz and Kearsley. The work of Kearsley was done under the direction of Professor Richard H. Rapp. The programming for the computations, computations themselves and graphical presentations for sections 4 and 5 of this report were done by Lenny Krieg.

Table of Contents

STUDIES IN GRAVIMETRIC GEODESY

1. Introduction

This is a final report and summary of the work done under the Contract No. F19628-77-C-0082. The contractual and reporting period is 1 January, 1977 - 30 September, 1978. Objectives of the work as defined in the contract were as follows:

a. Determine where a limited number of new absolute gravity measurements will have the largest influence on improving the IGSN 71 network; determine proper intervals for additional absolute sites in order to solve the second and higher order correction terms for calibration of gravimeters; determine the locations for new absolute measurements which reduce systematic errors to a minimum.

b. Study the Geodetic Boundary Value problem in light of the theoretical breakthrough of Lars Hörmander's "The Boundary-value Problem of Physical Geodesy", published in Stockholm, Sweden in 1975.

c. Study the homogeneity and isotropy assumptions in gravity predictions. Form models that vary from one area to another, and models that may have azimuth dependence in their covariance functions.

The work done on items b and c have been reported as Scientific Reports No. 2 and No. 1 respectively. The work done under item a has been reported in the quarterly status reports and in informal communications sent to the Monitor of the Contract.

In the following only a short summary will be given of work done under items b and c because the detailed technical reports, submitted earlier, cover the items in detail. More detailed report will be presented about the work done under item a.

2. Geodetic boundary value problem

The work done in this problem was reported in the technical report by Helmut Moritz (1977): "Recent Developments in the Geodetic Boundary-Value Problem." This report was submitted as Scientific Report No. 2 under this contract and was distributed by the Air Force Geophysic Laboratory as document AFGL-TR-78-0002. It was also distributed as Report No. 266 in the series of Reports of the Department of Geodetic Science.

The abstract of the report reads:

"The report reviews progress in the mathematical formulation and treatment of the geodetic boundary-value problem, in particular, the existence and uniqueness theorems of L. Hörmander and the gravity space approach due to F. Sanso. The method of Hörmander uses a very advanced inverse function theorem of non-linear functional analysis. Sanso has transformed Molodensky's free boundary-value problem into a fixed boundary-value problem in 'gravity space', thereby essentially reducing the mathematical complexity. As a linear approximation, the gravity space approach gives identical results to the conventional linearization, but gravity space appears superior for treating questions of existence and uniqueness of the solution, although it is restricted to the pure gravitational case without centrifugal force."

It is recommended that those who are interested in this subject matter read the original excellent technical report. The importance of this work might be reflected by the following quota-

tion from Moritz's report: "The impact of the gravity space approach to the theory of Molodensky's problem appears to be enormous; it may well be comparable to the impact of Hamiltonian methods to Newtonian classical mechanics (both apply a Legendre transformation!)."

3. Homogeneity and isotropy assumptions in gravity prediction

The work done in this problem was reported in the technical report by William Kearsley (1977): "Non-Stationary Estimation in Gravity Prediction Problems." This report was submitted as Scientific Report No. 1 under this contract and was distributed by the Air Force Geophysics Laboratory as document AFGL-TR-77-0186. It was also distributed as Report No. 256 in the series Reports of the Department of Geodetic Science.

The abstract of the report reads:

"This report investigates the impact that the assumptions of homogeneity and isotropy, when applied to potential related fields, have upon the stochastic processes which are applied to these fields. After seeing how these assumptions are incorporated into the statistical model to produce the familiar covariance function, the investigation centers on techniques which can be used to detect the presence of anisotropy in the field. The method found most useful in the two-dimensional covariance function, and some methods of representing this function are also investigated.

Numerical studies are then carried out to see the effect the use of the 2-D covariance function has upon the results of prediction and collocation computations. It is found that, under certain circumstances, the 2-D function produces a result superior to that given by the general function. Recommendations are then given as to when the 2-D covariance function should be used in practical solu-

tions, and suggestions made as to the possible areas of further research."

More details are reflected in the section of Conclusions in the report which reads:

"The two-dimensional covariance function provides the most efficient means of detecting and representing the anisotropic characteristics of a data set distributed over a plane. This function graphically describes the covariance which exists between point pairs of all separations and orientations. The extent of anisotropy is indicated by the departure of the contours of the 2-D covariance surface from a circular pattern, and the orientation of the axes of maximum and minimum correlation are clearly shown.

It is possible to model the 2-D covariance surface by generating a simple covariance function for each azimuth, $0 \leq \alpha < 360$. The logarithmic function suggested by Moritz (1976, p. 29) appears to be the best model overall, particularly when the function attains negative values. The fact that the 2-D cross-covariance function is not symmetrical complicates the generation of the surface by this method. It is possible to overcome this problem by using the symmetrical 2-D function to approximate the cross-covariance surface.

The ideal function would enable the generation of all auto and cross-covariance functions knowing the pertinent parameters of (say) the anomalous gravity field. The third-order Markov function suggested by Jordan (1972) has this capability. Unfortunately, the theoretical relationships did not agree with the actual relationships in this instance. It is felt that this is an important area for further research, if the usefulness of the 2-D covariance function is to be fully exploited.

The 2-D covariance function is capable of producing results superior to those obtained by the general function when certain

conditions are present. These conditions will produce large differences between elements of the covariance matrices derived from the general covariance analysis and from the 2-D covariance analysis. They will occur when:

(i) anisotropic effects are present and, because of the distribution of the data, predictions must be performed over large separations and in an asymmetric configuration, or

(ii) anisotropy is strongly evident and homogeneous throughout the field. Such an effect can be seen in areas where geoidal slope are uniformly and consistently large (e.g. the geoid slope across Australia). In fact, under these conditions the solution using the general function appears to break down.

In any case, a 2-D covariance analysis should be performed on data which shows anisotropic tendencies. This will indicate the extent to the azimuth dependence of the covariance function and enable remedial action to be taken (e.g. in the configuration of the data used in subsequent computation) if this appears warranted.

The 2-D covariance surface may also provide useful information concerning a suitable "trend surface" to be fitted to the original data. Knowing that the residuals of the actual data from the trend should be isotropic, it should be possible to discover what nature of surface must be fitted in order to transform the 2-D covariance surface to a surface of revolution. (This may be best performed in the spectral domain.) The residuals can then be used in the stochastic processes with the knowledge that they do in reality possess isotropic characteristics."

For more details the reader is referred to the original report.

4. Selection of preferred locations of new absolute gravity measurements in the gravity networks

4.1 Introduction

International Gravity Standardization Net 1971 [IGSN 71] was adopted by the International Union of Geodesy and Geophysics at the XV General Assembly in Moscow 1971 (Morelli, et al 1974). In the least squares adjustment which produced the IGSN 71 ten absolute measurements of gravity were used at the eight sites. Since the adoption of IGSN 71, new, very accurate, portable absolute gravity measuring devices have been developed. During the development phase of these apparatuses, a question "where is the best place to make an additional absolute gravity determination to improve most of the IGSN 71" was posed. Under this research project the analyses were performed in order to answer this question.

4.2 Mathematical model

The IGSN 71 is formed by 1854 gravity stations, distributed around the world. The inverse of the normal matrix for the solution of the gravity values of the stations and other parameters was available to us and obtained from the Defense Mapping Agency, Aerospace Center, Geodetic Survey Squadron, F.E. Warren AFB, Wyoming, where the final simultaneous adjustment of IGSN 71 was made. The analyses of the effect of new absolute measurements to the variance-covariance matrix can be accomplished using step-by-step sequential solutions. A brief outline of a procedure is given here following the notations and derivations given by Uotila (1973a).

Assuming we have a set of observations L_a^1 which are functions of a set of parameters, X_a:

$$L_a^1 = F_1(X_a). \tag{1}$$

If $$A_1 = \left.\frac{\partial F_1}{\partial X_a}\right|_{X_a = X_0}$$

where X_0 = approximate values of the parameters, we get linearized observation equations

$$V_1 = A_1 X_1 + L_1, \tag{2}$$

where V_1 = residuals

$X_1 = X_a^1 - X_0$

X_a^1 = adjusted values of parameters

$L_1 = L_0^1 - L_b^1$

L_b^1 = observed values

$L_0^1 = F_1(X_0)$.

The minimum variance solution gives us:

$$X_1 = -(A_1^T P_1 A_1)^{-1} A_1^T P_1 L_1 \tag{3}$$

where $P_1^{-1} = \Sigma_{L_b^1}$ variance-covariance matrix of observations L_b^1.

The adjusted values of parameters are:

$$X_a^1 = X_0 + X_1$$

and their variance-covariance matrix

$$\Sigma_{X_a^1} = (A_1^T P_1 A_1)^{-1} = N_1^{-1} \tag{4}$$

If we have the second set of observations L_b^2 and their variance-covariance matrix $\Sigma_{L_b^2} = P_2^{-1}$ and a mathematical model:

$$L_a^2 = F(X_a) \tag{5}$$

then a combined solution of the parameters is:

$$X_a^2 = X_0 + X_2 \tag{6}$$

where

$$X_2 = -(A_1^T P_1 A_1 + A_2^T P_2 A_2)^{-1}$$
$$(A_1^T P_1 A_1 + A_2^T P_2 L_2) \tag{7}$$

and

$$A_2 = \frac{\partial F_2}{\partial X_a}\bigg|_{X_a = X_0} , \quad L_2 = L_0^2 - L_b^2$$

$$L_0^2 = F_2(X_0)$$

The variance-covariance matrix of X_a^2 is:

$$\Sigma_{X_a^2} = (N_1 + A_2^T P_2 A_2)^{-1} \tag{8}$$

Equation (8) can be easily modified to (Uotila, 1973b):

$$\Sigma_{X_a^2} = N_1^{-1} - N_1^{-1} A_2^T (A_2 N_1^{-1} A_2^T + P_2^{-1})^{-1} A_2 N_1^{-1} \tag{9}$$

or

$$\Sigma_{X_a^1} - \Sigma_{X_a^2} = N_1^{-1} A_2^T (A_2 N_1^{-1} A_2^T + P_2^{-1})^{-1} A_2 N_1^{-1} \tag{10}$$

Equation (10) gives the difference of the variance-covariance matrix of parameters as obtained from the first set of observations and the variance-covariance matrix of parameters obtained using the first set of observations and the second set of observations combined. In our analyses $\Sigma_{X_a^1}$ could be the variance-covariance matrix of gravity values of IGSN 71 stations and $\Sigma_{X_a^2}$ the new variance-covariance matrix of the same gravity values after new absolute measurements have been added to the net. We are interested in this change in order to make the best site selections for new absolute measurements. Obviously the same kind of sequential solution can be continued by adding L_b^3 and getting $\Sigma_{X_a^3}$ using $\Sigma_{X_a^2}$ as starting matrix and so on. We could also add one observation at a time. For example, we can add a new observation at

each station, one at a time, and see the influence of each added observation to the original $\Sigma_{X_a^1}$. If we take all 1854 stations we would have equal number of $\Sigma_{X_a^1} - \Sigma_{X_a^2}$ differences. Now we must make a decision, which one of the new observations is giving the optimum change in the original variance-covariance matrix. When the selection is made we have a new $\Sigma_{X_a^2}$ for the net including a new selected absolute measurement. We can then find, using similar techniques, where the second absolute measurement should be made using the difference $\Sigma_{X_a^2} - \Sigma_{X_a^3}$. But how do we select the optimum $\Sigma_{X_a^1} - \Sigma_{X_a^2}$ from the 1854 possibilities?

According to Fedorov (1972) there are several properties which could be used to determine which one of the two experiments is the preferred one:

a) Experiment E_1 is preferred to experiment E_2 if the difference $\Sigma_{E_2} - \Sigma_{E_1}$ is a positive-definite matrix or in other words, $E_1 > E_2$ if $\Sigma_{E_1} < \Sigma_{E_2}$ where Σ_{E_1} and Σ_{E_2} are variance-covariance matrices of the corresponding results of the experiments.

b) The second criterion is

$E_1 > E_2$ if $|\Sigma_{E_1}| < |\Sigma_{E_2}|$

where $|\Sigma_{E_1}|$ and $|\Sigma_{E_2}|$ are determints of the variance-covariance matrices.

c) The third criterion is:

$E_1 > E_2$ if $\mathrm{Tr}\ \Sigma_{E_1} < \mathrm{Tr}\ \Sigma_{E_2}$

where $\mathrm{Tr}\ \Sigma_{E_1}$ and $\mathrm{Tr}\ \Sigma_{E_2}$ are traces of the variance-covariance matrices.

d) The fourth criterion is:

$E_1 > E_2$ if the maximum variance of E_1 < maximum variance of E_2.

e) $E_1 > E_2$ if the variance of a function of $E_1 <$ the variance of the same function of E_2. We could continue with this criteria of the function, including a - d criteria to a set of functions, but the above is sufficient to show that there are several possibilities for selecting criteria to decide which experiment is the "optimum."

Some test analyses were done and it was found that b and c of the criteria were not giving much different selections. The criteria c and d are fast computationally, but d reflects a local improvement and not necessarily global, therefore the c-criterion was selected to be used in these analyses.

If we have three matrices A, B and C of the same order and

$$A - B = C$$

then

$$Tr(A) - Tr(B) = Tr(C).$$

Letting $A = \Sigma_{X_a}^{1}$, $B = \Sigma_{X_a}^{2}$ and $C = N_1^{-1}A_2^T[A_2N_1^{-1}A_2^T + P_2^{-1}]^{-1} A_2N_1^{-1}$, it can be seen that the smallest Tr (B) is produced when the Tr (C) is largest since Tr (A) is invariant in this case. Thus, the problem of finding the optimum site for the first new absolute measurement is to find which one of the added observations maximizes the trace of C.

4.3 Computational technique

If a single, uncorrelated observation, which is a direct observation of a parameter, is added to the system, it turns out that the computation of the change in the trace is relatively fast and easy. Let's assume that a new absolute measurement of gravity is done at station i. We wish to evaluate the right side of the equation (10). A_2-matrix is a row matrix having zero elements except at i^{th} column there is +1, therefore $A_2N^{-1}A_2^T$ is a number equal to the

variance of gravity value of i^{th} station and P_2^{-1} is a number equal to the variance of the new absolute measurement at the i^{th} station. Therefore, $A_2N_1^{-1}A_2^T + P_2^{-1}$ is a sum of these two variances and its inverse is the reciprocal of this sum. The matrix product $N_1^{-1}A_2^T$ in this case will be equal to the i^{th} column of the N_1^{-1}-matrix and $A_2N_1^{-1}$ will be the i^{th} row of the N_1^{-1} matrix; therefore, for the change of the trace of C matrix (the right side of equation 10), we need the sum of the squares of the elements of i^{th} row of N_1^{-1} matrix multiplied by the reciprocal of sum of the variance of the gravity value of i^{th} station and the variance of the new absolute measurement.

The computational procedure described above turned out to be simple; therefore it is feasible to compute the change in the trace corresponding for each case, where each one of the stations was occupied by an absolute apparatus and a new absolute measurement of gravity was performed. The "optimum" station to be occupied first would be the station, which produced a maximum change in the trace as described above.

4.4 Variance-covariance matrix of IGSN 71 gravity values

The inverse of the normal matrix received from Geodetic Survey Squadron was not the variance-covariance matrix of gravity values of IGSN 71 stations, but a weight coefficient matrix. There was an unknown scale factor involved. It was solved by comparing variances derived from standard deviations given in (Morelli, et al, 1974) and diagonal elements of the matrix. Comparing 283 selected variances in IGSN 71 with corresponding elements of the matrix, it was found that the scale factor was 0.0037788. After multiplying the weight-coefficient matrix by 0.0037788, we obtained a variance-covariance matrix corresponding to the standard errors given in (Morelli, et al, 1974). A brief examination of standard errors given for IGSN 71 stations revealed that the standard errors seem to be too small.

For example, Washington, 11687 R has a standard deviation 0.011 mgal. The major contributor to the standard errors is the limited number of absolute measurements and their distribution in the net. Even if all ten absolute measurements used in the adjustment of IGSN 71 were done at a single site with accuracies stated in the publication (Morelli, et al, 1974), the standard error of the weighted mean would have been 0.0143 mgal; therefore it is impossible to have a standard error less than this value for any gravity value in IGSN 71 net. A closer look of weighting systems used in the final IGSN 71 suggested that there might have been a problem in relative weighting of the absolute measurements with other measurements. If that was the case, the gravity values of IGSN 71 would not change but variances for them would increase.

We had available a variance-covariance matrix of gravity values for 372 gravity stations computed by Uotila using linear correction term to calibration of gravimeters under AFCRL Contract No. F19628-68-C-0335. Comparing variances of 366 common stations it was found that the above obtained variance-covariance matrix of IGSN 71 should be multiplied by 1.90848 in order to have a reasonable agreement between these two variance-covariance matrices. Therefore, the original weight coefficient matrix of IGSN 71 was multiplied by 0.00721816 in order to obtain the variance-covariance matrix of gravity values of IGSN 71. That means that standard deviations given in IGSN 71 publications should be multiplied by $\sqrt{1.90848} \sim 1.38$, or, in other words, should be increased 38%.

4.5 Selection of the network to be analyzed

As was mentioned above there are 1854 stations in IGSN 71 network. Many of these stations having the same IGB-identification number are so called excentric stations and are highly correlated

with one another. An improvement in one would result an improvement in all excentric stations and the improvement in trace would reflect a strong local influence rather than a global one. To reduce this local dependency on the trace, a net of 422 stations was selected from the 1854 IGSN 71 net. The criterion for their selection was that no more than one station from given IGB number was included. Within a given IGB number the station with the most external ties was selected. See Table 1 listing of the stations and Figure 1 for the distribution of stations.

4.6 Results of analyses

4.6.1 World wide analyses

A few test runs were made with the net containing these 422 stations and assuming σ = 0.02 mgal accuracy for new absolute measurements of gravity. It was noticed that the stations having very large variance were selected as the best candidates for new absolute measurements. If these stations were really selected, there would be hardly any improvements elsewhere in the net except in the variance at these stations; therefore, the procedure was modified. We subtracted from the trace the improvement of the station, where the absolute measurement was made. This "partial trace" reflected better, in our opinion, an improvement in the whole global net.

The results of the new analyses gave the following priorities for new absolute measurements (using 0.02 mgal accuracy for the new absolute measurements):

1.	Nairobi	35716 A
2.	New Delhi	10187 K
3.	Rio Gallegos	51119 K

TABLE 1

GRAVITY BASE STATIONS USED IN THE ANALYSIS

U.S. NETS

Listing in IGB NUMBER order

CODE	IGB NUMBER	-----NAME-----------
	8141 O	KEY WEST
	8150 R	MIAMI
	8160 J	WEST PALM BEACH
	8170 K	VERO BEACH
U	8172 J	TAMPA
	8180 J	COCOA
	8181 K	ORLANDO
I	8191 J	DAYTONA BEACH
U	8191 O	DAYTONA BEACH
U	8277 J	CORPUS CHRIST
	8279 J	LAREDO
I	8289 B	COTULLA
	8290 J	NEW ORLEANS
	8295 J	HOUSTON
	8298 M	SAN ANTONIO
U	11629 J	CHARLESTON J
I	11629 L	CHARLESTON
	11649 J	FLORENCE/S.CAROLINA@
	11658 J	RALEIGH
	11677 J	RICHMOND
	11687 M	WASHINGTON
	11701 J	JACKSONVILLE
I	11711 J	BRUNSWICK
U	11711 K	BRUNSWICK
	11714 J	ALBANY
	11720 J	BEAUFORT
	11721 J	SAVANNAH
I	11734 J	ATLANTA
U	11734 K	ATLANTA
	11750 J	CHARLOTTE
	11753 J	KNOXVILLE
	11759 J	MEMPHIS
I	11785 J	LOUISVILLE
	11807 K	AUSTIN
	11826 J	DALLAS
	11842 J	LITTLE ROCK
	11877 J	WICHITA
I	11880 L	ST. LOUIS
U	11880 M	ST. LOUIS M M
I	11894 J	KANSAS CITY
U	11894 K	KANSAS CITY
	11916 J	EL PASO
I	11926 J	ALAMOGORDO
I	11931 J	LUBBOCK
	11951 J	AMARILLO
	11956 J	ALBUQUERQUE
I	11994 A	DENVER
U	11994 N	DENVER N CO
	11998 J	GRAND JUNCTION
	12027 K	SAN DIEGO
	12032 J	PHOENIX
	12038 K	LOS ANGELES
U	12047 K	NORTON AFB K
	12065 J	LAS VEGAS
	12099 J	RENO
	12172 O	SAN FRANCISCO
	12181 J	FAIRFIELD
	15148 J	BANGOR
	15167 J	CARIBOU
	15203 R	NEW YORK CITY
	15204 J	PRINCETON
	15209 J	PITTSBURG

Listing in ALPHABETICAL order

CODE	IGB NUMBER	-----NAME-----------
I	11926 J	ALAMOGORDO
	11714 J	ALBANY
	11956 J	ALBUQUERQUE
	11951 J	AMARILLO
I	11734 J	ATLANTA
U	11734 K	ATLANTA
	11807 K	AUSTIN
	15148 J	BANGOR
	11720 J	BEAUFORT
I	15558 L	BILLINGS
U	15558 M	BILLINGS M MT
	15560 K	BISMARCK
	15636 J	BOISE
	15221 J	BOSTON
I	11711 J	BRUNSWICK
U	11711 K	BRUNSWICK
	15228 J	BUFFALO
	15167 J	CARIBOU
	15526 L	CASPER
I	11629 L	CHARLESTON
U	11629 J	CHARLESTON J
	11750 J	CHARLOTTE
	15514 M	CHEYENNE
	15317 M	CHICAGO
	8180 J	COCOA
	15303 J	COLUMBUS
U	8277 J	CORPUS CHRIST
I	8289 B	COTULLA
U	15682 B	CUTBANK B
	11826 J	DALLAS
I	8191 J	DAYTONA BEACH
U	8191 O	DAYTONA BEACH
I	11994 A	DENVER
U	11994 N	DENVER N CO
	15323 J	DETROIT
I	15462 J	DULUTH
	11916 J	EL PASO
	12181 J	FAIRFIELD
I	15466 J	FARGO
	11649 J	FLORENCE/S.CAROLINA@
	15416 J	FREMONT
I	15477 M	GRAND FORKS
	11998 J	GRAND JUNCTION
	15671 L	GREAT FALLS
	8295 J	HOUSTON
	11701 J	JACKSONVILLE
I	11894 J	KANSAS CITY
U	11894 K	KANSAS CITY
	8141 O	KEY WEST
	11753 J	KNOXVILLE
	8279 J	LAREDO
	12065 J	LAS VEGAS
	11842 J	LITTLE ROCK
	12038 K	LOS ANGELES
I	11785 J	LOUISVILLE
I	11931 J	LUBBOCK
I	15339 A	MADISON
U	15339 J	MADISON J WI
I	15722 J	MEDFORD
	11759 J	MEMPHIS
	8150 R	MIAMI
I	15212 J	MIDDLETOWN

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

U.S. NETS (continued)

Listing in IGB NUMBER order

CODE	IGB NUMBER	-----NAME-----------
U	15212 A	MIDDLETOWN A
I	15212 J	MIDDLETOWN
	15221 J	BOSTON
	15228 J	BUFFALO
	15230 J	PORTLAND/MAINE@
	15236 J	SYRACUSE
	15303 J	COLUMBUS
	15317 M	CHICAGO
	15323 J	DETROIT
I	15339 A	MADISON
U	15339 J	MADISON J WI
U	15414 J	STUART
	15416 J	FREMONT
	15426 J	SIOUX CITY
	15436 J	SIOUX FALLS
	15443 L	MINNEAPOLIS
I	15462 J	DULUTH
I	15466 J	FARGO
I	15477 M	GRAND FORKS
	15514 M	CHEYENNE
	15526 L	CASPER
	15543 J	RAPID CITY
	15546 J	SHERIDAN
I	15558 L	BILLINGS
U	15558 M	BILLINGS M MT
	15560 K	BISMARCK
I	15581 L	MINOT
I	15601 J	SALT LAKE CITY
U	15601 K	SALT LAKE CIT
I	15611 J	OGDEN
	15636 J	BOISE
	15671 L	GREAT FALLS
I	15677 J	SPOKANE
U	15682 B	CUTBANK B
I	15722 J	MEDFORD
	15752 J	PORTLAND/OREGON@
	15772 P	SEATTLE

Listing in ALPHABETICAL order

CODE	IGB NUMBER	-----NAME-----------
U	15212 A	MIDDLETOWN A
	15443 L	MINNEAPOLIS
I	15581 L	MINOT
	8290 J	NEW ORLEANS
	15203 R	NEW YORK CITY
U	12047 K	NORTON AFB K
I	15611 J	OGDEN
	8181 K	ORLANDO
	12032 J	PHOENIX
	15209 J	PITTSBURG
	15230 J	PORTLAND/MAINE@
	15752 J	PORTLAND/OREGON@
	15204 J	PRINCETON
	11658 J	RALEIGH
	15543 J	RAPID CITY
	12099 J	RENO
	11677 J	RICHMOND
U	15601 K	SALT LAKE CIT
I	15601 J	SALT LAKE CITY
	8298 M	SAN ANTONIO
	12027 K	SAN DIEGO
	12172 O	SAN FRANCISCO
	11721 J	SAVANNAH
	15772 P	SEATTLE
	15546 J	SHERIDAN
	15426 J	SIOUX CITY
	15436 J	SIOUX FALLS
I	15677 J	SPOKANE
I	11880 L	ST. LOUIS
U	11880 M	ST. LOUIS M M
U	15414 J	STUART
	15236 J	SYRACUSE
U	8172 J	TAMPA
	8170 K	VERO BEACH
	11687 M	WASHINGTON
	8160 J	WEST PALM BEACH
	11877 J	WICHITA

NORTH AMERICAN NETS excluding U.S. NETS

CODE	IGB NUMBER	NAME
U	889 A	PANAMA A
I	889 M	PANAMA
U	899 J	CRISTOBAL
	994 K	SAN JOSE
	4526 K	MANAGUA
	4539 K	SAN SALVADOR
	4640 K	GUATEMALA
U	4640 M	GUATEMALA M
	4669 K	ACAPULCO
	4698 A	PASO DE CORTES
	4699 A	MEXICO CITY
	8320 K	SAN LUIS POTOSI
	8350 K	MONTERREY
	15239 J	TORONTO
	15253 J	MONTREAL
	15255 J	OTTAWA
	15261 J	QUEBEC
	15282 J	ROBERVAL
	15497 O	WINNIPEG
	15692 A	LETHBRIDGE
U	15793 J	VANCOUVER J
I	15793 M	VANCOUVER
	18730 J	GOOSE BAY

CODE	IGB NUMBER	NAME
	4669 K	ACAPULCO
I	23119 K	ANCHORAGE
U	23119 J	ANCHORAGE J
	26703 J	BARTER ISLAND
	19214 J	CALGARY
	22361 J	CAPE DYER
U	19084 R	CHURCHILL R
U	899 J	CRISTOBAL
U	23049 K	DAWSON
	19233 M	EDMONTON
	26195 K	EUREKA
	23147 K	FAIRBANKS
	18788 J	FORT CHIMO
U	19382 J	FORT NELSON
	19360 L	FORT ST. JOHN
	22338 J	FROBISHER BAY
	18730 J	GOOSE BAY
	19258 K	GRANDE PRAIRIE
	4640 K	GUATEMALA
U	4640 M	GUATEMALA M
	22581 J	HALL BEACH
	15692 A	LETHBRIDGE
I	22485 J	LONGSTAFF

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

NORTH AMERICAN NETS excluding U.S. NETS (continued)

Listing in IGB NUMBER order				Listing in ALPHABETICAL order			
CODE	IGB NUMBER		-----NAME-----------	CODE	IGB NUMBER		-----NAME-----------
	18746	J	SCHEFFERVILLE		4526	K	MANAGUA
	18788	J	FORT CHIMO		4699	A	MEXICO CITY
U	19084	R	CHURCHILL R		8350	K	MONTERREY
	19214	J	CALGARY		15253	J	MONTREAL
	19223	A	RED DEER		26469	O	MOULD BAY
	19233	M	EDMONTON	U	23121	B	NORTHWAY
	19258	K	GRANDE PRAIRIE		15255	J	OTTAWA
	19360	L	FORT ST. JOHN	I	889	M	PANAMA
U	19382	J	FORT NELSON	U	889	A	PANAMA A
	22338	J	FROBISHER BAY		4698	A	PASO DE CORTES
	22361	J	CAPE DYER		26816	A	POINT BARROW
I	22485	J	LONGSTAFF		15261	J	QUEBEC
	22581	J	HALL BEACH		19223	A	RED DEER
	22908	L	WATSON LAKE		26244	K	RESOLUTE BAY
	23005	A	WHITEHORSE		15282	J	ROBERVAL
U	23049	K	DAWSON		994	K	SAN JOSE
U	23119	J	ANCHORAGE J		8320	K	SAN LUIS POTOSI
I	23119	K	ANCHORAGE		4539	K	SAN SALVADOR
U	23120	A	SNAG		18746	J	SCHEFFERVILLE
U	23121	B	NORTHWAY	U	23120	A	SNAG
	23147	K	FAIRBANKS		15239	J	TORONTO
	26195	K	EUREKA	I	15793	M	VANCOUVER
	26244	K	RESOLUTE BAY	U	15793	J	VANCOUVER J
	26469	O	MOULD BAY		22908	L	WATSON LAKE
	26703	J	BARTER ISLAND		23005	A	WHITEHORSE
	26816	A	POINT BARROW		15497	O	WINNIPEG

WORLD NETS excluding NORTH AMERICAN NETS

	150	K	ACCRA	U	41752	J	MARYBOROUGH
I	154	L	ABIDJAN	I	154	L	ABIDJAN
I	260	K	MONROVIA		150	K	ACCRA
I	293	J	CONAKRY		3398	K	ADDIS ABABA
	655	J	PARAMARIBO		6824	J	ADEN
	668	J	GEORGETOWN		10909	J	AGADIR
U	793	K	MATURIN		18040	J	AGEN
	826	K	POPAYAN		10177	J	AGRA
	836	K	CALI		10132	J	AHMEDABAD
	844	K	BOGOTA	I	45466	K	ALBURY
	865	K	MEDELLIN	I	29522	J	ALERT
U	2087	J	KWAJALEIN	I	14463	J	ALGIERS
	2613	A	SINGAPORE	I	14385	T	ALI TERME
U	2622	J	MALACCA	I	[illegible]933	J	ALICE SPRINGS
	2631	J	KUALA LUMPUR		[illegible]093	J	ALTA
	2650	J	PENANG	I	[illegible]3714	J	AMRITSAR
	2670	J	SONGKHLA	U	[illegible]7904	J	ANGRI J
	2969	J	COLOMBO	I	14192	J	ANKARA
	3302	J	ENTEBBE		4371	J	ANTIGUA
	3398	K	ADDIS ABABA		40430	K	ANTOFAGASTA
I	3548	J	BANGUI	I	21572	K	APELVIKSAAS
	3609	B	LIBREVILLE	U	21572	J	APELVIKSAAS J
	3649	J	DOUALA		36861	K	AREQUIPA
	3663	J	LAGOS		36880	K	ARICA
I	3728	J	BAMAKO		32674	J	ASCENSION ISLAND
	3836	J	BATHURST	I	6958	K	ASMARA
	3846	J	MBOUR-DAKAR	U	6958	A	ASMARA A
	3885	J	NOUAKCHOTT		40257	J	ASUNCION
U	3962	J	CAPE VERDE IS	I	10542	K	ASWAN
	4301	J	PORT OF SPAIN	U	45164	C	AUCKLAND
	4306	K	CARACAS		11187	J	AZORES
I	4341	J	ST. LUCIA	I	21510	A	BAD HARZBURG
	4371	J	ANTIGUA	U	21510	C	BAD HARZBURG
I	4374	J	ST. CROIX	I	21609	J	BAD HERSFELD

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE I (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order

CODE	IGB NUMBER		NAME
	4386	J	SAN JUAN
	4387	K	RAMEY
	4404	J	BARRANQUILLA
I	4476	J	KINGSTON
U	4476	L	KINGSTON L
I	4482	J	PORT AU PRINCE
I	4487	J	MONTEGO BAY
I	4495	J	GUANTANAMO
U	5295	J	HAWAII ISLAND
U	5696	J	WAKE ISLAND J
I	5696	N	WAKE ISLAND
	5834	N	GUAM
	6050	L	MANILA
	6206	J	SAIGON
	6230	J	BANGKOK
U	6230	M	BANKOK
	6366	K	RANGOON
I	6430	J	MADRAS
I	6537	J	BANGALORE
I	6578	J	HYDERABAD
I	6592	J	BOMBAY
	6824	J	ADEN
	6952	K	KHARTOUM
I	6956	J	TESSENEI
U	6958	A	ASMARA A
I	6958	K	ASMARA
	6997	K	PORT SUDAN
I	7228	J	KANO
I	7232	J	NIAMEY
	7407	J	PORT ETIENNE
	7485	J	GRAND CANARY
	8806	C	MAUI ISLAND
	8817	J	OAHU-HONOLULU
I	9087	J	MIDWAY
	9651	J	TAIPEI
	9667	J	KADENA
	9724	L	HONG KONG
	10028	J	CALCUTTA
	10052	J	BANARAS
	10060	J	LUCKNOW
	10132	J	AHMEDABAD
	10143	J	UDAIPUR
	10165	J	JAIPUR
	10177	J	AGRA
	10187	K	NEW DELHI
	10511	K	WADI HALFA
I	10542	K	ASWAN
I	10552	K	LUXOR
	10591	M	CAIRO
	10909	J	AGADIR
	10937	J	CASABLANCA
	10955	J	TANGIER
U	10966	K	ROTA
	10989	K	LISBON
	11187	J	AZORES
	11524	J	BERMUDA
U	11524	K	BERMUDA
I	13080	A	TOHOKU
	13110	A	KAGOSHIMA
	13120	A	KUMAMOTO
U	13130	A	KYUSHU
	13145	J	ITAMI
	13155	C	KYOTO
I	13159	C	TOKYO

Listing in ALPHABETICAL order

CODE	IGB NUMBER		NAME
	21500	L	BAD NEUSTADT
	43982	K	BAHIA BLANCA
I	3728	J	BAMAKO
	17990	B	BAMBERG SUD
	10052	J	BANARAS
I	6537	J	BANGALORE
	6230	J	BANGKOK
I	3548	J	BANGUI
U	6230	M	BANKOK
	18012	J	BARCELONA
	25198	K	BARDUFOSS
	4404	J	BARRANQUILLA
	3836	J	BATHURST
	46622	J	BEAUFORT WEST
	14135	J	BEIRUT
	32918	L	BELEM
I	36593	J	BELO HORIZONTE
	11524	J	BERMUDA
U	11524	K	BERMUDA
I	17905	L	BIVIO GIUNGANO
	25174	J	BODO
	844	K	BOGOTA
I	6592	J	BOMBAY
U	21523	W	BRANDENBURG
	21520	C	BRAUNSCHWEIG
I	36557	J	BRAZILIA
I	21638	K	BREMEN
	41773	J	BRISBANE
	46603	J	BRISTOWN
I	21604	S	BRUSSELS
U	21604	L	BRUSSELS
I	43848	J	BUENOS AIRES
U	43848	K	BUENOS AIRES
I	43008	K	BULAWAYO
I	21523	V	BURG
	38265	A	CAIRNS
	10591	M	CAIRO
	10028	J	CALCUTTA
	836	K	CALI
I	40111	J	CAMPOS
	45459	J	CANBERRA
I	43858	J	CANUELAS
U	3962	J	CAPE VERDE IS
I	46738	A	CAPETOWN
U	46738	K	CAPETOWN K
	4306	K	CARACAS
I	36479	J	CARAVELAS
	47503	K	CARMEN DE PATAGONES
I	32977	J	CAROLINA
	10937	J	CASABLANCA
U	17930	N	CASTIGLIONCEL
U	14375	B	CATANIA B
I	14395	N	CETRARO
	18070	K	CHATEAU RENAULT
	48732	K	CHRISTCHURCH
U	38726	J	COCOS ISL. J
	17961	J	COLLE ISARCO
	2969	J	COLOMBO
	47557	K	COMODORO RIVADAVIA
I	293	J	CONAKRY
I	21552	K	COPENHAGEN
U	21552	C	COPENHAGEN C
	43914	K	CORDOBA
	35769	K	DAR ES SALAAM

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order				Listing in ALPHABETICAL order			
CODE	IGB NUMBER		-----NAME-----------	CODE	IGB NUMBER		-----NAME-----------
U	13159	N	TOKYO N	I	38320	A	DARWIN
U	13276	J	SEOUL	U	38320	J	DARWIN J
I	13707	J	MOHAN		13708	A	DEHRA DUN
	13708	A	DEHRA DUN	U	14395	L	DIAMANTE
I	13714	J	AMRITSAR		3649	J	DOUALA
I	13849	J	KABUL		48750	D	DUNEDIN
I	13951	J	TEHERAN	I	18153	J	EDINBURGH
	14112	K	PORT SAID	U	18153	O	EDINBURGH
	14135	J	BEIRUT		21550	P	EIBY
I	14192	J	ANKARA		3302	J	ENTEBBE
	14323	A	TRIPOLI	I	14374	T	ETNA KM 15-16
U	14374	P	ETNA P	U	14374	P	ETNA P
I	14374	T	ETNA KM 15-16		14386	J	FALERNA MARINA
U	14375	B	CATANIA B		25175	J	FAUSKE
I	14375	X	S. BERNARDO	I	17941	F	FERRARA
U	14385	J	GALATI J	I	40178	J	FLORIANOPOLIS
I	14385	T	ALI TERME		25142	R	FORMOFOSS
	14386	J	FALERNA MARINA		32838	J	FORTALEZA
U	14395	L	DIAMANTE	I	21608	O	FRANKFURT
I	14395	N	CETRARO	U	21608	P	FRANKFURT P
	14396	J	S. LUCIDO	U	21609	T	FULDA
I	14463	J	ALGIERS	U	14385	J	GALATI J
	14492	J	MALLORCA		668	J	GEORGETOWN
	14503	M	MADRID	I	18154	P	GLASGOW
	16601	J	MISAWA	I	36569	J	GOIANA
	16631	K	SAPPORO	I	41792	K	GRAFTON
I	16651	A	WAKKANAI		7485	J	GRAND CANARY
U	17904	J	ANGRI J		5834	N	GUAM
I	17904	P	LICOLA	I	4495	J	GUANTANAMO
U	17905	J	PONTE FARAONE		33229	K	GUAYAQUIL
I	17905	L	BIVIO GIUNGANO		59520	J	HALLETT
I	17912	A	ROME		25101	K	HAMAR
U	17912	N	ROME N		21639	B	HAMBURG
	17913	N	MINTURNO		28603	A	HAMMERFEST
	17921	J	PODERE SPINETA	U	21629	A	HANNOVER A
I	17930	J	QUERCETA	I	21629	K	HANOVER
U	17930	N	CASTIGLIONCEL		45196	J	HASTINGS
I	17940	J	LUZZARA	U	5295	J	HAWAII ISLAND
U	17940	P	RICO		21521	J	HELMSTEDT
I	17941	F	FERRARA	U	21562	J	HELSINGBORG J
	17950	J	PERI	I	21562	T	HELSINGOR
	17951	G	ROVERETO	I	25004	A	HELSINKI
	17961	J	COLLE ISARCO	U	25004	S	HELSINKI S
U	17971	K	INNSBRUCK	I	25229	U	HJERKINN
I	17971	X	STAFFLACH	U	21581	J	HOGSTORP J
	17972	L	NIEDERAUDORF		9724	L	HONG KONG
U	17981	C	MUNICH C	I	6578	J	HYDERABAD
I	17981	J	MUNICH	U	17971	K	INNSBRUCK
	17990	B	BAMBERG SUD		40400	K	IQUIQUE
U	17991	D	NURNBERG	I	33233	J	IQUITOS
I	17991	P	NEUSES		13145	J	ITAMI
	18012	J	BARCELONA		25087	J	IVALO
	18022	J	PERPIGNAN		10165	J	JAIPUR
	18030	L	TARBES		43068	L	JOHANNESBURG
	18031	J	TOULOUSE	I	13849	J	KABUL
I	18033	J	NARBONNE		9667	J	KADENA
I	18035	C	MARSEILLES		13110	A	KAGOSHIMA
U	18037	J	NICE	I	7228	J	KANO
	18040	J	AGEN	U	21619	R	KASSEL OST
	18049	R	PIASTRA	I	45312	J	KEMPSEY
	18050	J	MONTIGNAC		6952	K	KHARTOUM
	18059	J	MILAN		43084	K	KIMBERLEY
	18060	K	POITIERS	I	4476	J	KINGSTON
	18070	K	CHATEAU RENAULT	U	4476	L	KINGSTON L

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order				Listing in ALPHABETICAL order			
CODE	IGB NUMBER		-----NAME-----------	CODE	IGB NUMBER		-----NAME-----------
	18082	O	PARIS		35945	M	KINSHASA/LEOPOLDVILL
I	18110	A	TEDDINGTON		2631	J	KUALA LUMPUR
U	18110	J	TEDDINGTON J		13120	A	KUMAMOTO
I	18153	J	EDINBURGH	U	2087	J	KWAJALEIN
U	18153	O	EDINBURGH		13155	C	KYOTO
I	18154	P	GLASGOW	U	13130	A	KYUSHU
I	18165	J	OBAN	I	36768	A	LA PAZ
	21500	L	BAD NEUSTADT	U	36768	J	LA PAZ J
I	21510	A	BAD HARZBURG		3663	J	LAGOS
U	21510	C	BAD HARZBURG		46630	J	LAINGBURG
	21520	C	BRAUNSCHWEIG		25165	K	LEIRJORDFALL
	21521	J	HELMSTEDT		3609	B	LIBREVILLE
I	21523	A	POTSDAM	I	17904	P	LICOLA
I	21523	V	BURG		25110	P	LILLEHAMMER
U	21523	W	BRANDENBURG		36827	K	LIMA
	21530	L	STOOKELDORF-FACKENBU		10989	K	LISBON
I	21540	J	RICKLING	U	43055	B	LOBATSI
	21550	P	EIBY	U	42952	J	LOURENCO MARQ
	21551	J	RINGSTED		35983	J	LUANDA
U	21552	C	COPENHAGEN C		10060	J	LUCKNOW
I	21552	K	COPENHAGEN		39458	J	LUSAKA
U	21562	J	HELSINGBORG J	I	10552	K	LUXOR
I	21562	T	HELSINGOR	I	17940	J	LUZZARA
	21563	J	VEINGE KE.		41819	J	MACKAY
	21571	J	S. KRISTINA	I	6430	J	MADRAS
U	21572	J	APELVIKSAAS J		14503	M	MADRID
I	21572	K	APELVIKSAAS		25131	K	MAERE
U	21581	J	HOGSTORP J		25153	K	MAJAVATN
I	21581	Q	TANUM	U	2622	J	MALACCA
	21590	K	OSLO		14492	J	MALLORCA
	21591	J	SVINESUNDE	I	33039	J	MANAUS
I	21597	K	STOCKHOLM		6050	L	MANILA
U	21604	L	BRUSSELS	I	59637	J	MARBLE POINT J
I	21604	S	BRUSSELS	I	18035	C	MARSEILLES
I	21608	O	FRANKFURT	I	41752	A	MARYBOROUGH
U	21608	P	FRANKFURT P	U	793	K	MATURIN
I	21609	J	BAD HERSFELD		8806	C	MAUI ISLAND
U	21609	T	FULDA		42707	J	MAURITIUS ISLAND
U	21619	R	KASSEL OST	U	42961	B	MBABANE
I	21619	V	MELSUNGEN-BEUERN	I	35783	K	MBEYA
U	21629	A	HANNOVER A		3846	J	MBOUR-DAKAR
I	21629	K	HANOVER		59676	C	MCMURDO SOUND
I	21629	R	SOLTAU		865	K	MEDELLIN
I	21638	K	BREMEN		45474	M	MELBOURNE
	21639	B	HAMBURG	I	21619	V	MELSUNGEN-BEUERN
	21649	F	RENDSBURG		21659	J	MIDDELFART
	21659	J	MIDDELFART	I	9087	J	MIDWAY
I	21716	P	TVERAA		18059	J	MILAN
	21941	K	REYKJAVIK		17913	N	MINTURNO
U	22270	J	SONDRESTROMFJ		16601	J	MISAWA
I	25004	A	HELSINKI		25164	K	MO-I-RANA
U	25004	S	HELSINKI S	I	13707	J	MOHAN
I	25045	J	OULU	U	35749	D	MOMBASA
	25065	J	ROVANEIMI	I	260	K	MONROVIA
	25087	J	IVALO	I	4487	J	MONTEGO BAY
I	25090	J	SORKJOSEN		43846	K	MONTEVIDEO
	25093	J	ALTA		18050	J	MONTIGNAC
	25101	K	HAMAR	I	35737	K	MOSHI
	25110	P	LILLEHAMMER	I	41909	J	MT. ISA
	25120	J	SOKNEDAL	I	17981	J	MUNICH
	25130	L	TRONDHEIM	U	17981	C	MUNICH C
	25131	K	MAERE	I	35716	A	NAIROBI
	25142	R	FORMOFOSS	U	35716	N	NAIROBI N
	25143	J	VEISKILLE		37977	J	NANDI-FIJI ISLAND

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order

CODE	IGB NUMBER	-----NAME-----------
	25153 K	MAJAVATN
I	25163 J	SKAMDAL
	25164 K	MO-I-RANA
	25165 K	LEIRJORDFALL
	25174 J	BODO
	25175 J	FAUSKE
	25187 K	NARVIK
	25198 K	BARDUFOSS
	25199 J	TROMSO
	25219 Q	VINSTRA
U	25229 L	OPPDAL L
I	25229 U	HJERKINN
	25968 K	THULE
	28603 A	HAMMERFEST
I	29522 J	ALERT
	32674 J	ASCENSION ISLAND
	32838 J	FORTALEZA
U	32884 J	RECIFE J
I	32884 L	RECIFE
	32918 L	BELEM
I	32977 J	CAROLINA
I	33039 J	MANAUS
I	33134 J	TEFE
	33208 K	QUITO
	33229 K	GUAYAQUIL
I	33233 J	IQUITOS
	33341 K	TALARA
I	35716 A	NAIROBI
U	35716 N	NAIROBI N
I	35737 K	MOSHI
U	35749 D	MOMBASA
	35769 K	DAR ES SALAAM
I	35783 K	MBEYA
	35945 M	KINSHASA/LEOPOLDVILL
	35983 J	LUANDA
I	36428 J	SALVADOR
I	36479 J	CARAVELAS
I	36508 J	PORTO NATIONAL
I	36557 J	BRAZILIA
I	36569 J	GOIANA
I	36593 J	BELO HORIZONTE
I	36768 A	LA PAZ
U	36768 J	LA PAZ J
U	36773 J	SANTA CRUZ
	36827 K	LIMA
	36861 K	AREQUIPA
	36880 K	ARICA
U	37579 B	TAHITI
U	37841 J	PAGO PAGO
I	37841 L	PAGO PAGO
	37977 J	NANDI-FIJI ISLAND
	38265 A	CAIRNS
	38296 N	TOWNSVILLE
I	38320 A	DARWIN
U	38320 J	DARWIN J
U	38726 J	COCOS ISL. J
	39371 M	SALISBURY
	39428 K	NDOLA
	39458 J	LUSAKA
	39475 K	VICTORIA FALLS
I	39525 J	NOVA LISBOA J
I	39543 J	SA DA BANDEIRA
	40100 J	VITORIA
I	40111 J	CAMPOS

Listing in ALPHABETICAL order

CODE	IGB NUMBER	-----NAME-----------
I	18033 J	NARBONNE
	25187 K	NARVIK
	39428 K	NDOLA
I	17991 P	NEUSES
	10187 K	NEW DELHI
I	7232 J	NIAMEY
U	18037 J	NICE
	17972 L	NIEDERAUDORF
	3885 J	NOUAKCHOTT
I	39525 J	NOVA LISBOA J
U	17991 D	NURNBERG
	8817 J	OAHU-HONOLULU
I	18165 J	OBAN
U	25229 L	OPPDAL L
	40334 K	ORAN
	21590 K	OSLO
I	25045 J	OULU
I	37841 L	PAGO PAGO
U	37841 J	PAGO PAGO
	655 J	PARAMARIBO
	18082 O	PARIS
I	43812 J	PELOTAS
	2650 J	PENANG
	17950 J	PERI
	18022 J	PERPIGNAN
I	45715 P	PERTH
U	45715 A	PERTH A
	18049 R	PIASTRA
I	43039 K	PIETERSBURG
	17921 J	PODERE SPINETA
	18060 K	POITIERS
U	17905 J	PONTE FARAONE
	826 K	POPAYAN
I	4482 J	PORT AU PRINCE
	7407 J	PORT ETIENNE
	4301 J	PORT OF SPAIN
	14112 K	PORT SAID
	6997 K	PORT SUDAN
I	43801 J	PORTO ALEGRE
I	36508 J	PORTO NATIONAL
I	21523 A	POTSDAM
	43058 A	PRETORIA
	47575 K	PUERTO DESEADO
I	47612 J	PUERTO MONTT
	51108 K	PUERTO SANTA CRUZ
	51230 L	PUNTA ARENAS
I	17930 J	QUERCETA
	33208 K	QUITO
	4387 K	RAMEY
	6366 K	RANGOON
I	32884 L	RECIFE
U	32884 J	RECIFE J
	21649 F	RENDSBURG
	21941 K	REYKJAVIK
I	21540 J	RICKLING
U	17940 P	RICO
	21551 J	RINGSTED
	43934 K	RIO CUARTO
	40123 A	RIO DE JANEIRO
	51119 K	RIO GALLEGOS
	51137 L	RIO GRANDE
	41730 K	ROCKHAMPTON
I	17912 A	ROME
U	17912 N	ROME N

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order

CODE	IGB NUMBER		-----NAME-----------
	40123	A	RIO DE JANEIRO
	40136	J	SAO PAULO
I	40178	J	FLORIANOPOLIS
	40257	J	ASUNCION
	40334	K	ORAN
	40345	K	SALTA
	40365	L	TUCUMAN
	40374	K	SANTIAGO ESTERO
	40400	K	IQUIQUE
	40420	K	TOCOPILLA
	40430	K	ANTOFAGASTA
	41730	K	ROCKHAMPTON
I	41752	A	MARYBOROUGH
U	41752	J	MARYBOROUGH
	41773	J	BRISBANE
I	41792	K	GRAFTON
	41819	J	MACKAY
I	41909	J	MT. ISA
I	41933	J	ALICE SPRINGS
	42707	J	MAURITIUS ISLAND
U	42952	J	LOURENCO MARQ
U	42961	B	MBABANE
I	43008	K	BULAWAYO
I	43039	K	PIETERSBURG
U	43055	B	LOBATSI
	43058	A	PRETORIA
	43068	L	JOHANNESBURG
	43084	K	KIMBERLEY
I	43801	J	PORTO ALEGRE
I	43812	J	PELOTAS
	43846	K	MONTEVIDEO
I	43848	J	BUENOS AIRES
U	43848	K	BUENOS AIRES
I	43858	J	CANUELAS
	43914	K	CORDOBA
	43920	K	ROSARIO
	43934	K	RIO CUARTO
	43982	K	BAHIA BLANCA
I	44030	A	SANTIAGO
U	44030	K	SANTIAGO K
U	44031	K	VALPARAISO
U	45164	C	AUCKLAND
	45196	J	HASTINGS
I	45312	J	KEMPSEY
	45331	J	SYDNEY
	45459	J	CANBERRA
I	45466	K	ALBURY
	45474	M	MELBOURNE
U	45715	A	PERTH A
I	45715	P	PERTH
	46603	J	BRISTOWN
	46622	J	BEAUFORT WEST
	46630	J	LAINGBURG
I	46738	A	CAPETOWN
U	46738	K	CAPETOWN K
	47503	K	CARMEN DE PATAGONES
	47535	K	TRELEW
	47557	K	COMODORO RIVADAVIA
	47575	K	PUERTO DESEADO
	47597	K	SAN JULIAN
I	47612	J	PUERTO MONTT
	48714	K	WELLINGTON
	48732	K	CHRISTCHURCH
	48750	D	DUNEDIN

Listing in ALPHABETICAL order

CODE	IGB NUMBER		-----NAME-----------
	43920	K	ROSARIO
U	10966	K	ROTA
	25065	J	ROVANEIMI
	17951	C	ROVERETO
I	14375	X	S. BERNARDO
	21571	J	S. KRISTINA
	14396	J	S. LUCIDO
I	39543	J	SA DA BANDEIRA
	6206	J	SAIGON
	39371	M	SALISBURY
	40345	K	SALTA
I	36428	J	SALVADOR
	4386	J	SAN JUAN
	47597	K	SAN JULIAN
U	36773	J	SANTA CRUZ
I	44030	A	SANTIAGO
	40374	K	SANTIAGO ESTERO
U	44030	K	SANTIAGO K
	40136	J	SAO PAULO
	16631	K	SAPPORO
U	13276	J	SEOUL
	2613	A	SINGAPORE
I	25163	J	SKAMDAL
	25120	J	SOKNEDAL
I	21629	R	SOLTAU
U	22270	J	SONDRESTROMFJ
	2670	J	SONGKHLA
I	25090	J	SORKJOSEN
I	4374	J	ST. CROIX
I	4341	J	ST. LUCIA
I	17971	X	STAFFLACH
I	21597	K	STOCKHOLM
	21530	L	STOOKELDORF-FACKENBU
	21591	J	SVINESUNDE
	45331	J	SYDNEY
U	37579	B	TAHITI
	9651	J	TAIPEI
	33341	K	TALARA
	10955	J	TANGIER
I	21581	Q	TANUM
	18030	L	TARBES
I	18110	A	TEDDINGTON
U	18110	J	TEDDINGTON J
I	33134	J	TEFE
I	13951	J	TEHERAN
I	6956	J	TESSENEI
	25968	K	THULE
	40420	K	TOCOPILLA
I	13080	A	TOHOKU
I	13159	C	TOKYO
U	13159	N	TOKYO N
	18031	J	TOULOUSE
	38296	N	TOWNSVILLE
	47535	K	TRELEW
	14323	A	TRIPOLI
	25199	J	TROMSO
	25130	L	TRONDHEIM
	40365	L	TUCUMAN
I	21716	P	TVERAA
	10143	J	UDAIPUR
	51148	L	USHUAIA
U	44031	K	VALPARAISO
	21563	J	VEINCE KE.
	25143	J	VEISKILLE

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

TABLE 1 (continued)

WORLD NETS excluding NORTH AMERICAN NETS (continued)

Listing in IGB NUMBER order

CODE	IGB NUMBER	-----NAME-----------
	51108 K	PUERTO SANTA CRUZ
	51119 K	RIO GALLEGOS
	51137 L	RIO GRANDE
	51148 L	USHUAIA
	51230 L	PUNTA ARENAS
	59520 J	HALLETT
I	59637 J	MARBLE POINT J
	59676 C	MCMURDO SOUND

Listing in ALPHABETICAL order

CODE	IGB NUMBER	-----NAME-----------
	39475 K	VICTORIA FALLS
	25219 Q	VINSTRA
	40100 J	VITORIA
	10511 K	WADI HALFA
I	5696 N	WAKE ISLAND
U	5696 J	WAKE ISLAND J
I	16651 A	WAKKANAI
	48714 K	WELLINGTON

CODE: I => IGSN71 net only, U => UAU net only, NO CODE => common to both nets

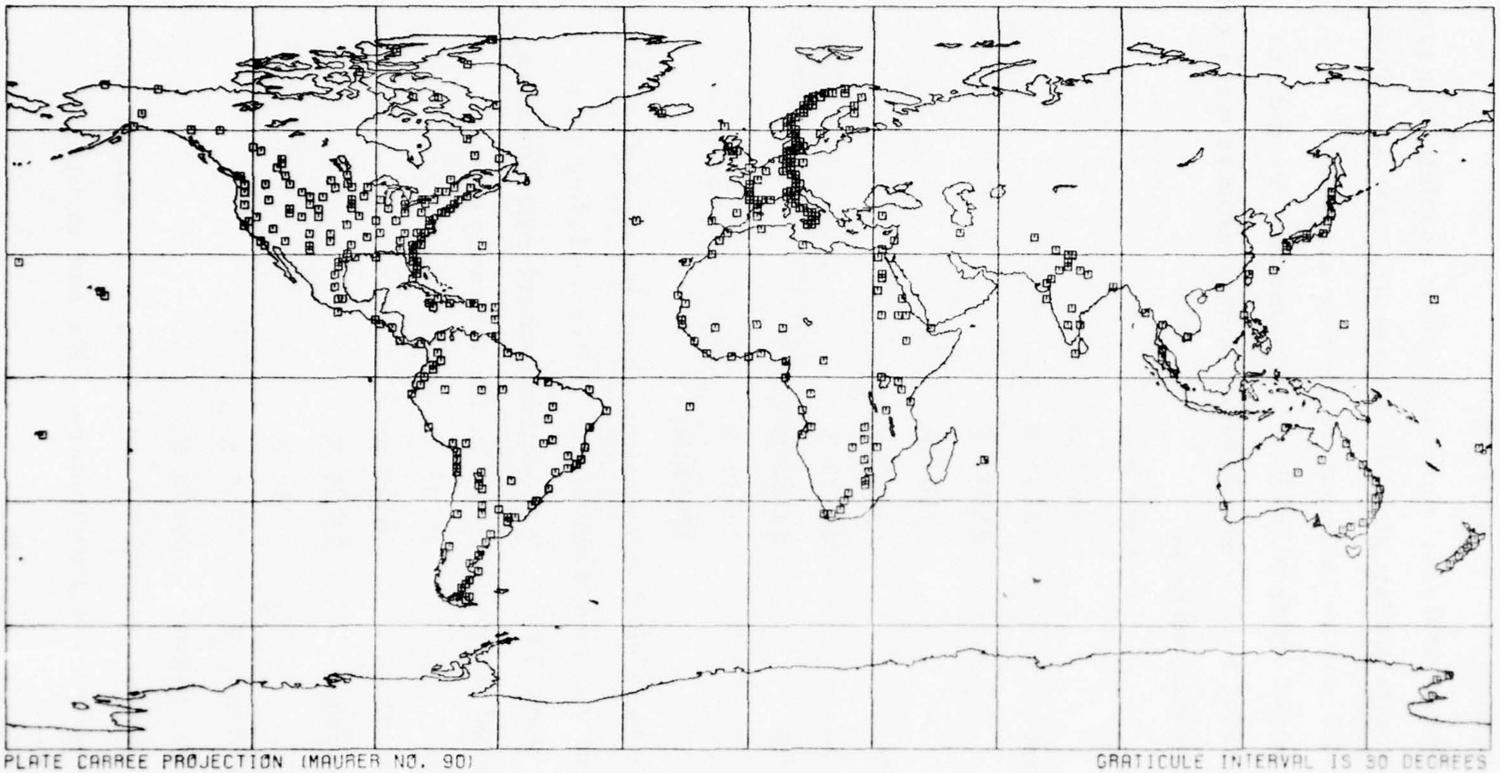

FIGURE 1 - DISTRIBUTION OF STATIONS IN THE "IGSN" WORLD NET

4.	Bogota	884 K
5.	Bodo	25174 J
6.	Maryborough	41752 A.

During and after these analyses were done, new absolute measurements were made with Italian absolute apparatus. All new absolute measurements could not be included in the new analyses because they were not made at IGSN 71 stations and we did not have information about ties. New absolute measurements were considered at the following stations:

Teddington	18110 A
Rome	17912 A
Hammerfest	28603 A
Helsinki	25004 A
Munich	17981 A
Copenhagen	21552 K
S. Bernardo	14375 X
Brunschweig	21520 C
Hamburg	21639 B
Paris	18082 O.

We did not have good information about the accuracy of these measurements, but we used 0.02 mgal. After including these measurements in IGSN 71 net, the stations where new absolute measurements should be made came in the following order:

1.	Nairobi	35716 A
2.	New Delhi	10187 K
3.	Rio Gallegos	51119 K
4.	Bogota	884 K
5.	Rockhampton	41730 K
6.	McMurdo Sound	59676 C.

In the adjustment of IGSN 71 only linear corrections were solved for the scales of the gravimeters. We had in hand a

variance-covariance matrix for the gravity values solved under the AFCRL Contract No. F19628-68-C-0335 (UAU-net), which included also the second order corrections to scales of the gravimeters. We did the analyses for this net which included 372 gravity stations distributed around the world, listed in Table 1 and shown in Figure 2.

Two separate analyses were done: 1) original net and 2) original net plus ten new absolute measurements listed above. In the order of preference six new sites for future absolute measurements were selected as follows:

1) Original net

1.	Panama	889 A
2.	Thule	25968 K
3.	Nairobi	35176 N
4.	Washington	11687 M
5.	Sydney	45331 J
6.	Bodo	25174 J.

2) With new absolute measurements

1.	Paso De Cortes	4698 A
2.	Singapore	2613 A
3.	Thule	25968 K
4.	Azores	11187 J
5.	Nairobi	35716 N
6.	Buenos Aires	43848 K.

These two nets; IGSN 71 and the UAU-net do not include the same observations and not necessarily the same stations as seen in Table 1. The latter one included the same pendulum and absolute measurements as IGSN 71 but from gravimeter ties only those which were made with La Coste-Romberg gravimeters were included in the adjustment of the UAU-net. When we looked at the distribution of the selected stations for new absolute measurements, it is our opinion that this latter selection might be a better one. It also

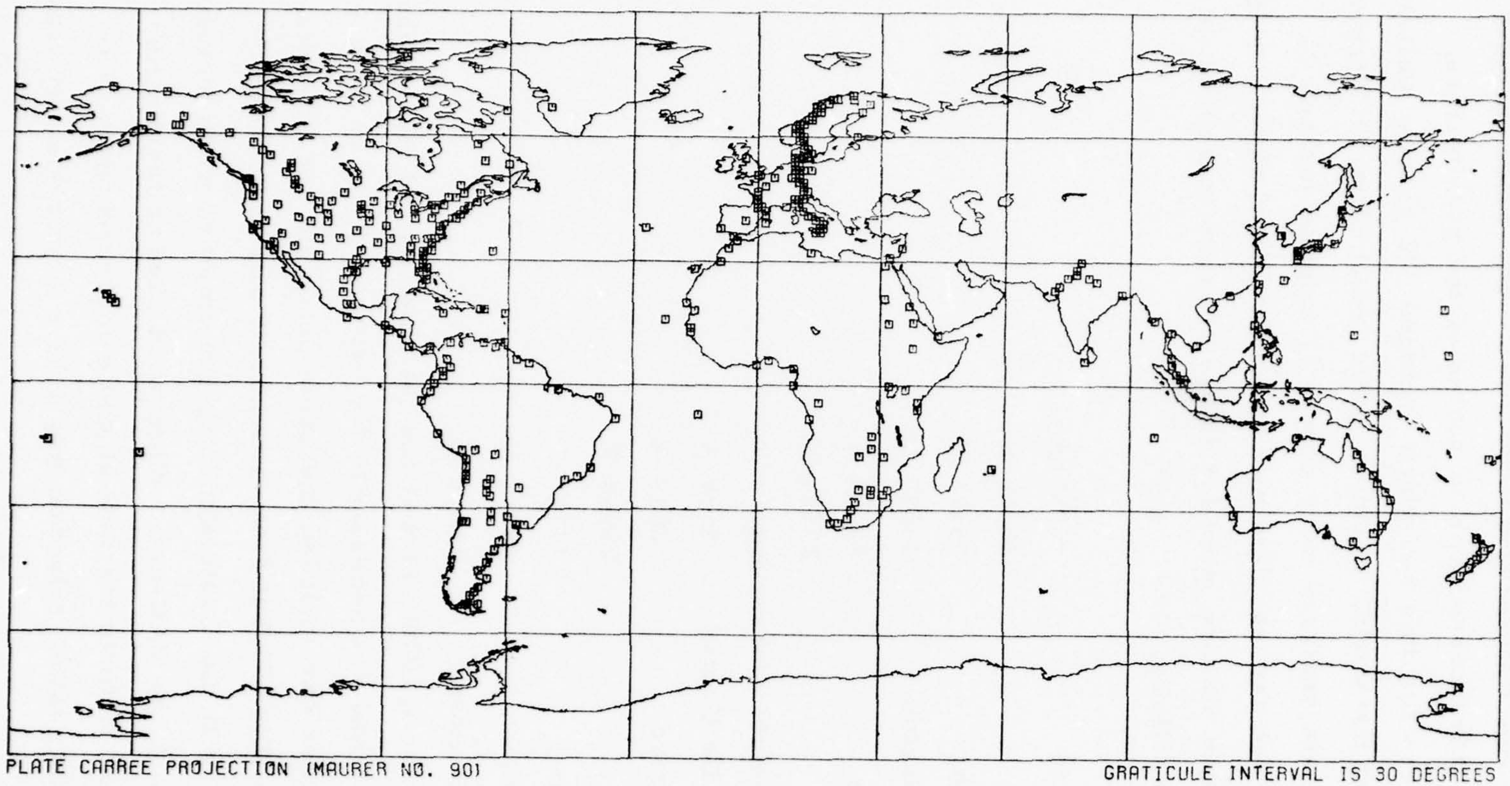

FIGURE 2 - DISTRIBUTION OF STATIONS IN THE "UAU" WORLD NET

is supposed to control better the second order influence in the scale factors.

More detailed analyses showed that after the new absolute measurements in Europe, new proposed absolute measurements contributed hardly anything to the European net. The contributions of new absolute measurements have become more continental and local rather than global. It has become obvious that we do not gain much through old gravimeter connections between continents. If we wish to improve world wide net, the best improvements are coming from new absolute measurements on different continents. It also shows that the best approach to improve IGSN 71 net is to do readjustments of continental or local nets rather than a new adjustment of the global net. Even new gravimeter ties between continents with the currently available instruments will not change much the situation.

4.6.2 African network

Outside of the contract we made analyses of African portion of IGSN 71 net as a favor to African nations, who were planning to establish new absolute gravity sites in Africa. We selected the stations from IGSN 71 net which fell in Africa plus Paris and Rome, where new absolute measurements had been made at that time (March, 1977). We wanted to see if these same selection criteria could be used for a smaller part of the world net. The preferred order of new absolute measurements came as follows:

1.	Kinshasa	35945	M
2.	Nairobi	35716	A
3.	Mbour-Dakar	3846	J
4.	Lusaka	39458	J
5.	Casablanca	10937	J

6.	Luxor	10552 K
7.	Douala	3649 J
8.	Nova Lisboa	39575 J
9.	Beaufort West	46622 J
10.	Dar Es Salaam	35769 K
11.	Asmara	6958 K
12.	Port Etienne	7407 J
13.	Damako	3728 J
14.	Bulawayo	43008 K
15.	Monrovia	260 K
16.	Cairo	10591 M.

This net included only the stations which were in IGSN 71 net. Therefore, it might not be the best for Africa as far as a new base station net is concerned. It might be necessary to establish more dense net taking into consideration existing gravity measurements and a future use of the net. However, analyses of the results indicated that the program was making the logical choices as far as the IGSN 71 improvements were concerned.

4.6.3 North American and U.S. Gravity Base Station nets

During the summer of 1977 the negotiations were going on to bring Italian absolute apparatus to the United States for inter-comparison purposes. We were asked by Project Monitor, Bela Szabo to analyze the U.S. portion of IGSN 71 net for the preferred locations of new absolute measurements. Three versions were studied:

1. Stations in North America.
2. Stations in North America but selected stations for absolute measurements to be located in the United States, excluding Alaska.
3. Stations in the United States excluding Alaska and Hawaii.

All of the above three alternatives were analyzed in two ways:

a) considering stations in IGSN 71 and the variance-covariance matrix from the solution, where only linear correction term to calibration of gravimeters were included;

b) considering the UAU-network and the variance-covariance matrix obtained from the solution, which included linear and second order correction terms to the calibration of gravimeters.

In Table 1 the stations belonging to the U.S. networks are identified as well as other stations belonging to the North American nets.

All of the above mentioned alternatives were examined. During the analyses not only the preferred order was determined for the new absolute measurements, but several quantities were computed, such as the trace of variance-covariance matrix, the partial trace of the same matrix as explained earlier, new variances of the gravity values of the stations, average variances for the stations, changes in variances and percentage changes of variances. These quantities were computed after each cycle for each station included in the solutions. In the following three tables, 2, 3 and 4, the solutions using 122 stations in North America are summarized. The selected stations are given in order of preference. In these analyses it was assumed that the new absolute measurements have an accuracy, σ = 20 μgal. Table 2 gives results for both of the networks and the average variances of stations in North America at the beginning and after each addition of the absolute measurement. In these solutions there were no preselected stations for absolute measurements. They were "free solutions."

Table 3 gives the selections of preferred stations considering the effect of new absolute measurements in the whole North American nets, but constraining the selected stations to be located inside

Table 2
North American Base Station Nets
Free Solution

Accuracy of Absolute Measurements σ = 20 μgal

IGSN 71-Net 122 Stations, $\bar{\sigma}^2$ = 711 μgal^2		UAU-Net 122 Stations, $\bar{\sigma}^2$ = 1776 μgal^2	
Selected Stations	$\bar{\sigma}^2$ μgal^2	Selected Stations	$\bar{\sigma}^2$ μgal^2
1. Mexico City	626	1. Monterrey	1255
2. Hall Beach	588	2. Point Barrow	808
3. Dallas	562	3. Paso De Corte	684
4. Jacksonville	545	4. Washington	621
5. Edmonton	531	5. Great Falls	591
6. San Jose	518	6. Resolute Bay	561
7. Mould Bay	488	7. San Francisco	544
8. Minneapolis	479	8. Denver	534

Table 3
North American Base Station Nets
Free Solutions but Stations to be
Selected in U.S.A.

Accuracy of Absolute Measurements σ = 20 μgal

IGSN 71-Net 122 Stations, $\bar{\sigma}^2$ = 711 μgal^2		UAU-Net 122 Stations, $\bar{\sigma}^2$ = 1776 μgal^2	
Selected Stations	$\bar{\sigma}^2$ μgal^2	Selected Stations	$\bar{\sigma}^2$ μgal^2
1. Miami	639	1. Miami	1274
2. San Antonio	609	2. Denver	1187
3. Great Falls	588	3. Seattle	1122
4. Orlando	574	4. Miami	1078
5. Minneapolis	562	5. Washington	1044
6. Albuquerque	552	6. El Paso	1021
7. Seattle	543	7. Caribou	999
8. Louisville	534	8. San Francisco	987

Table 4
North American Base Station Nets
Denver and Boston Preselected Stations
All Stations Selected in the U.S.A.

Accuracy of Absolute Measurements $\sigma = 20\ \mu gal$

IGSN 71-Net 122 Stations, $\bar{\sigma}^2 = 711\ \mu gal^2$		UAU-Net 122 Stations, $\bar{\sigma}^2 = 1776\ \mu gal^2$	
Selected Stations	$\bar{\sigma}^2\ \mu gal^2$	Selected Stations	$\bar{\sigma}^2\ \mu gal^2$
Denver		Denver	
Boston	630	Boston	1337
1. Miami	597	1. Miami	1143
2. San Antonio	580	2. Miami	1097
3. Seattle	566	3. Seattle	1052
4. Orlando	556	4. Cheyenne	1026
5. Bismarck	547	5. El Paso	1005
6. El Paso	538	6. Seattle	986

Table 5
U.S. Base Station Nets
Free Solution

Accuracy of Absolute Measurement $\sigma = 20\ \mu gal$

IGSN71-Net 83 Stations, $\bar{\sigma}^2 = 576\ \mu gal^2$		UAU-Net 77 Stations, $\bar{\sigma}^2 = 1030\ \mu gal^2$	
Selected Stations	$\bar{\sigma}^2\ \mu gal^2$	Selected Stations	$\bar{\sigma}^2\ \mu gal^2$
1. Miami	499	1. Houston	631
2. Dallas	466	2. Denver	555
3. San Francisco	446	3. Washington	519
4. Charleston	430	4. Miami	485
5. Louisville	413	5. Great Falls	465
6. Bismarck	401	6. Orlando	452
7. Albuquerque	392	7. Madison	440
8. Orlando	385	8. Albuquerque	432

of the United States excepting Alaska. Table 4 gives the solutions for the North American nets with same constraints as in Table 3 and in the addition the condition that Boston and Denver have been preselected to be the sites of the new absolute measurements.

Tables 5-9 give results for various situations in the U.S. base station nets. We have first two solutions for the free choice of the stations without any preselected stations, given in Table 5 and 6. The only difference between these solutions is that in Table 5 the accuracy of absolute measurements is assumed to be $\sigma = 20$ μgal and in Table 6 $\sigma = 10$ μgal. The orders of selections are different but the average variances have not improved much - only 13% even though the accuracy of absolute measurements has been improved 50%. This small return from improvement of accuracies of absolute measurements points out that the gravity differences between stations must be measured more accurately in order to benefit fully from the improved accuracies of absolute measurements. This additional accuracy from absolute measurements will improve only local situations or those stations which are tied more accurately than average to the stations where absolute measurements are made.

It is interesting to note that if new absolute measurements were done at eight sites, then there would not be much difference in IGSN 71, if all stations were selected freely in the North America or in the U.S.A. There is even less difference if the sites were freely selected in the U.S.A. or two of the stations were preselected in the same area. However, if we take the UAU-network which includes the second order terms, there is a large difference in the average variances if the station selection is limited to the area of the U.S.A., but not much effect is seen by preselecting two of the stations as compared with the "free solution" in the U.S.A. We can also see that after 4-5 new absolute measurements the gain in the whole U.S. net is not much - the improvements will be more

of a local nature. Tables 7-9 give the U.S. networks after 2, 4 and 5 stations have been preselected. It is again interesting to see that a reasonable preselection of stations does not influence much the average variances in the whole net. In Table 9 the average variance in UAU-net is even smaller than in Table 5, which is a "free solution." We have to remember that the selections of the stations have been made using "the partial trace" of variance-covariance matrices in order to minimize the influence of local stations; therefore, the full trace of the variance-covariance matrix is not necessarily minimum for the preferred choices.

It is clear that if we make more than six new absolute measurements, we do not gain much as far as the current base station networks are concerned. Larger improvements can be expected if new, more accurate measurements of gravity differences between the stations are established.

Since these studies were concluded and informally reported to Project Monitor, the new absolute measurements have been carried out at Bedford, Denver, Bismarck, Miami, San Francisco and Alamogordo, which corresponds about the situation given in Table 8 after two selections. Therefore, it is appropriate to give expected variances to all stations included in the U.S.A. portion of the UAU-net. The old variances and the new ones are given in Table 10. As we can see in the UAU-net there are five stations which are poorly tied to any other stations, namely Tampa, Corpus Christy, San Diego, Norton AFB and Portland. If a full trace would have been used in selection, these stations would possibly have come up as the first choices, but the whole net would not have been improved much. The variances of these stations are keeping the average variance large.

For easy reference the changes in the variance are given in Table 11. This table clearly reflects that the last two new

Table 6
U.S. Base Station Nets
Free Solution

Accuracy of Absolute Measurements σ = 10 μgal

IGSN 71-Net 83 Stations, $\bar{\sigma}^2$ = 576 μgal^2		UAU-Net 77 Stations, $\bar{\sigma}^2$ = 1030 μgal^2	
Selected Stations	$\bar{\sigma}^2$ μgal^2	Selected Stations	$\bar{\sigma}^2$ μgal^2
1. Dallas	450	1. Denver	515
2. Orlando	418	2. Miami	458
3. Minneapolis	396	3. Great Falls	418
4. Louisville	378	4. Washington	405
5. Charleston	365	5. San Antonio	396
6. San Francisco	355	6. Boston	390
7. Minot	344	7. Kansas City	382
8. Albuquerque	336	8. Orlando	377

Table 7
U.S. Base Station Nets
Boston and Denver Preselected Stations

Accuracy of Absolute Measurements σ = 20 μgal

IGSN 71-Net 83 Stations, $\bar{\sigma}^2$ = 576 μgal^2		UAU-Net 77 Stations, $\bar{\sigma}^2$ = 1030 μgal^2	
Selected Stations	$\bar{\sigma}^2$ μgal^2	Selected Stations	$\bar{\sigma}^2$ μgal^2
Denver		Denver	
Boston	486	Boston	609
1. Miami	453	1. Miami	512
2. Albuquerque	434	2. Denver	486
3. Charleston	419	3. Orlando	469
4. Bismarck	407	4. Great Falls	452
5. Louisville	393	5. San Antonio	442
6. Dallas	386	6. Madison	432

Table 8
U.S. Base Station Nets
Boston, Denver, Albuquerque, and Bismarck
Preselected Stations

Accuracy of Absolute Measurements $\sigma = 20\ \mu gal$

IGSN 71-Net 83 Stations, $\bar{\sigma}^2 = 576\ \mu gal^2$			UAU-Net 77 Stations, $\bar{\sigma}^2 = 1030\ \mu gal^2$		
	Selected Stations	$\bar{\sigma}^2\ \mu gal^2$		Selected Stations	$\bar{\sigma}^2\ \mu gal^2$
	Denver			Denver	
	Boston			Boston	
	Bismarck			Albuquerque	
	Albuquerque	440		Bismarck	505
1.	Jacksonville	420	1.	Miami	468
2.	Louisville	405	2.	San Francisco	458
3.	Miami	395	3.	Orlando	441
4.	Charleston	387	4.	Madison	432

Table 9
U.S. Base Station Nets
Boston, Denver, Albuquerque, Bismarck
and Columbus Preselected Stations

Accuracy of Absolute Measurements $\sigma = 20\ \mu gal$

IGSN 71-Net 83 Stations, $\bar{\sigma}^2 = 576\ \mu gal^2$			UAU-Net 77 Stations, $\bar{\sigma}^2 = 1030\ \mu gal^2$		
	Selected Stations	$\bar{\sigma}^2\ \mu gal^2$		Selected Stations	$\bar{\sigma}^2\ \mu gal^2$
	Denver			Denver	
	Boston			Boston	
	Albuquerque			Albuquerque	
	Bismarck			Columbus	
	Columbus	425		Bismarck	489
1.	Jacksonville	407	1.	Miami	453
2.	Miami	397	2.	Orlando	440
3.	Charleston	388	3.	San Francisco	430

TABLE 10 - VARIANCES IN MIRCOGAL SQUARED

SUMMARY OF RESULTS FOR UAU'S U.S. NET AFTER ADDING # DENVER N CO (20): # BOSTON J MA (20): # ALBUQUERQUE J (20): # BISMARCK K ND (20): MIAMI R FL (20): SAN FRANCISCO (20): ORLANDO K FL (20): MADISON J WI (20):

ROW	IGB	NAME	LAT	LON	ORIG.	PRE-S	SEL-1	SEL-2	SEL-3	SEL-4
1	11687 M	WASHINGTON M	38	283	489	131	125	106	102	90
2	11994 N	DENVER N CO	39	256	727	135	106	90	79	74
3	15212 A	MIDDLETOWN A	41	288	466	210	209	195	194	182
4	15221 J	BOSTON J MA	42	289	392	129	129	117	116	104
5	8141 O	KEY WEST O FL	24	279	1732	716	520	518	475	474
6	8150 R	MIAMI R FL	25	280	1330	376	194	191	154	154
7	8160 J	WEST PALM BEA	26	280	1321	434	291	287	243	243
8	8170 K	VERO BEACH	27	280	1371	516	390	384	337	337
9	8172 J	TAMPA	27	278	6179	5329	5228	5217	5183	5183
10	8180 J	COCOA J FL	28	280	1358	521	418	411	377	377
11	8181 K	ORLANDO K FL	28	279	1105	286	176	170	119	119
12	8191 O	DAYTONA BEACH	29	279	1055	319	235	227	192	191
13	8277 J	CORPUS CHRIST	27	263	4041	3148	3036	3026	2994	2994
14	8279 J	LAREDO	27	261	1476	527	401	396	362	362
15	8290 J	NEW ORLEANS	29	270	1121	358	270	261	238	237
16	8295 J	HOUSTON J TX	29	265	1029	235	154	145	121	120
17	8298 M	SAN ANTONIO M	29	262	1124	270	174	167	139	139
18	11629 J	CHARLESTON J	32	281	819	217	168	156	136	133
19	11649 J	FLORENCE SC	34	281	817	279	245	231	216	211
20	11658 J	RALEIGH	35	282	694	211	188	172	161	154
21	11677 J	RICHMOND	37	283	671	257	244	227	220	211
22	11701 J	JACKSONVILLE	30	279	987	279	203	194	163	161
23	11711 K	BRUNSWICK	31	279	1052	378	312	302	276	274
24	11714 J	ALBANY	31	276	1339	671	609	599	570	567
25	11720 J	BEAUFORT	32	280	1152	538	488	476	455	452
26	11721 J	SAVANNAH	32	279	946	307	250	239	215	213
27	11734 K	ATLANTA	33	276	1068	428	379	367	349	346
28	11750 J	CHARLOTTE	35	280	757	237	207	192	179	173
29	11753 J	KNOXVILLE	35	277	843	304	274	258	246	240
30	11759 J	MEMPHIS	35	271	839	304	277	261	251	244
31	11807 K	AUSTIN K TX	30	263	1099	301	221	212	188	188
32	11826 J	DALLAS J TX	32	264	850	193	146	133	117	114
33	11842 J	LITTLE ROCK	34	268	806	267	242	225	216	209
34	11877 J	WICHITA	37	263	846	345	334	317	312	303
35	11880 M	ST. LOUIS M M	38	270	851	437	431	413	409	393
36	11894 K	KANSAS CITY	39	266	814	391	387	368	365	352
37	11916 J	EL PASO J TX	31	254	1408	413	305	301	272	272
38	11951 J	AMARILLO J TX	35	259	977	252	201	189	173	170
39	11956 J	ALBUQUERQUE J	35	254	1203	232	174	169	152	152
40	11998 J	GRAND JUNCTIO	39	252	892	289	259	242	231	226
41	12027 K	SAN DIEGO	32	243	2081	1437	1395	1369	1355	1352
42	12032 J	PHOENIX J AZ	33	248	1015	307	272	258	247	244
43	12038 K	LOS ANGELES K	33	242	912	276	250	233	223	219
44	12047 K	NORTON AFB K	34	243	3247	2599	2559	2543	2529	2525

TABLE 10 - VARIANCES IN MIRCOGAL SQUARED (continued)

SUMMARY OF RESULTS FOR UAU'S U.S. NET AFTER ADDING # DENVER N CO (20): # BOSTON J MA (20):
ALBUQUERQUE J (20): # BISMARCK K ND (20): MIAMI R FL (20): SAN FRANCISCO (20): ORLANDO K FL (20):
MADISON J WI (20):

ROW	IGB	NAME	LAT	LON	ORIG.	PRE-S	SEL-1	SEL-2	SEL-3	SEL-4
45	12065 J	LAS VEGAS J N	36	245	976	350	323	307	297	293
46	12099 J	RENO J NV	39	241	904	343	318	289	280	275
47	12172 O	SAN FRANCISCO	37	238	573	154	147	108	104	95
48	12181 J	FAIRFIELD J	38	239	663	248	241	209	205	196
49	15148 J	BANGOR J ME	44	292	426	218	218	207	207	192
50	15167 J	CARIBOU J	46	293	469	293	292	283	283	267
51	15203 R	NEW YORK CITY	40	287	513	196	194	177	175	160
52	15204 J	PRINCETON J N	40	286	462	156	153	136	132	120
53	15209 J	PITTSBURGH J	40	281	712	347	342	324	321	307
54	15228 J	BUFFALO J NY	42	282	529	257	257	240	239	220
55	15230 J	PORTLAND ME.	43	290	505	279	279	267	266	252
56	15236 J	SYRACUSE	43	284	529	267	266	252	251	236
57	15303 J	COLUMBUS OH	40	277	811	433	429	410	407	392
58	15317 M	CHICAGO M IL	41	273	568	267	266	247	246	217
59	15323 J	DETROIT	42	277	607	318	318	299	298	274
60	15339 J	MADISON J WI	43	271	443	167	167	149	148	108
61	15414 J	STUART	41	266	1135	822	821	801	800	775
62	15416 J	FREMONT	41	264	1160	818	816	796	794	770
63	15426 J	SIOUX CITY J	42	264	593	285	284	266	266	248
64	15436 J	SIOUX FALLS J	43	264	573	281	281	264	263	245
65	15443 L	MINNEAPOLIS L	44	267	413	187	187	173	173	149
66	15514 M	CHEYENNE M WY	41	256	704	151	125	108	98	92
67	15526 L	CASPER L WY	42	254	618	180	171	152	148	137
68	15543 J	RAPID CITY J	44	257	620	275	274	257	256	243
69	15546 J	SHERIDAN J WY	44	254	485	156	154	135	133	118
70	15558 M	BILLINGS M MT	45	252	458	164	164	147	147	131
71	15560 K	BISMARCK K ND	46	260	526	190	190	182	182	172
72	15601 K	SALT LAKE CIT	40	249	718	220	204	180	173	165
73	15636 J	BOISE J ID	43	244	630	296	295	267	266	253
74	15671 L	GREAT FALLS L	47	249	388	150	150	133	133	115
75	15682 B	CUTBANK B	48	248	4367	4152	4151	4136	4136	4118
76	15752 J	PORTLAND J OR	45	238	467	260	259	239	238	221
77	15772 P	SEATTLE P WA	47	238	425	240	238	225	224	206
AVERAGE VARIANCE IN MIRCOGAL SQUARED					1030	505	468	454	441	432
CHANGE IN AVERAGE VARIANCE						524	37	15	13	9

TABLE 11 - CHANGES IN VARIANCES IN MIRCOGAL SQUARED

SUMMARY OF RESULTS FOR UAU'S U.S. NET AFTER ADDING # DENVER N CO (20): # BOSTON J MA (20): # ALBUQUERQUE J (20): # BISMARCK K ND (20): MIAMI R FL (20): SAN FRANCISCO (20): ORLANDO K FL (20): MADISON J WI (20):

ROW	ICB		NAME	LAT	LON	PRE-S	SEL-1	SEL-2	SEL-3	SEL-4
1	11687	M	WASHINGTON M	38	283	358	6	19	4	12
2	11994	N	DENVER N CO	39	256	592	30	16	11	5
3	15212	A	MIDDLETOWN A	41	288	256	1	14	2	12
4	15221	J	BOSTON J MA	42	289	263	0	12	1	12
5	8141	O	KEY WEST O FL	24	279	1016	196	2	44	0
6	8150	R	MIAMI R FL	25	280	953	182	3	37	0
7	8160	J	WEST PALM BEA	26	280	887	144	4	44	0
8	8170	K	VERO BEACH	27	280	856	126	5	47	0
9	8172	J	TAMPA	27	278	850	101	10	34	0
10	8180	J	COCOA J FL	28	280	837	103	7	34	0
11	8181	K	ORLANDO K FL	28	279	820	110	6	51	0
12	8191	O	DAYTONA BEACH	29	279	736	84	8	35	1
13	8277	J	CORPUS CHRIST	27	263	893	111	11	32	0
14	8279	J	LAREDO	27	261	949	126	4	35	0
15	8290	J	NEW ORLEANS	29	270	762	88	9	23	1
16	8295	J	HOUSTON J TX	29	265	794	81	9	24	1
17	8298	M	SAN ANTONIO M	29	262	853	96	7	28	0
18	11629	J	CHARLESTON J	32	281	602	49	12	20	4
19	11649	J	FLORENCE SC	34	281	538	34	14	15	5
20	11658	J	RALEIGH	35	282	482	23	16	11	7
21	11677	J	RICHMOND	37	283	414	13	17	7	9
22	11701	J	JACKSONVILLE	30	279	708	76	9	32	1
23	11711	K	BRUNSWICK	31	279	674	66	10	27	2
24	11714	J	ALBANY	31	276	667	62	10	29	2
25	11720	J	BEAUFORT	32	280	614	50	11	21	3
26	11721	J	SAVANNAH	32	279	639	57	11	24	3
27	11734	K	ATLANTA	33	276	640	49	13	17	3
28	11750	J	CHARLOTTE	35	280	520	29	15	13	6
29	11753	J	KNOXVILLE	35	277	539	30	16	12	6
30	11759	J	MEMPHIS	35	271	535	26	16	10	6
31	11807	K	AUSTIN K TX	30	263	798	80	9	24	1
32	11826	J	DALLAS J TX	32	264	656	47	13	15	3
33	11842	J	LITTLE ROCK	34	268	539	25	17	9	7
34	11877	J	WICHITA	37	263	501	10	18	5	9
35	11880	M	ST. LOUIS M M	38	270	414	6	19	3	16
36	11894	K	KANSAS CITY	39	266	423	5	19	3	13
37	11916	J	EL PASO J TX	31	254	995	108	4	29	0
38	11951	J	AMARILLO J TX	35	259	726	51	11	17	2
39	11956	J	ALBUQUERQUE J	35	254	971	57	5	17	0
40	11998	J	GRAND JUNCTIO	39	252	602	30	17	11	5
41	12027	K	SAN DIEGO	32	243	644	42	26	14	3
42	12032	J	PHOENIX J AZ	33	248	708	35	13	12	3
43	12038	K	LOS ANGELES K	33	242	636	26	17	9	4
44	12047	K	NORTON AFB K	34	243	648	40	17	14	3

TABLE 11 - CHANGES IN VARIANCES IN MIRCOGAL SQUARED (continued)

SUMMARY OF RESULTS FOR UAU'S U.S. NET AFTER ADDING * DENVER N CO (20): * BOSTON J MA (20):
* ALBUQUERQUE J (20): * BISMARCK K ND (20): MIAMI R FL (20): SAN FRANCISCO (20): ORLANDO K FL (20):
MADISON J WI (20):

ROW	IGB	NAME	LAT	LON	PRE-S	SEL-1	SEL-2	SEL-3	SEL-4
45	12065 J	LAS VEGAS J N	36	245	626	27	17	10	5
46	12099 J	RENO J NV	39	241	561	25	30	9	5
47	12172 O	SAN FRANCISCO	37	238	419	7	40	3	9
48	12181 J	FAIRFIELD J	38	239	415	8	32	4	10
49	15148 J	BANGOR J ME	44	292	208	0	11	0	14
50	15167 J	CARIBOU J	46	293	176	1	10	0	16
51	15203 R	NEW YORK CITY	40	287	317	2	17	2	15
52	15204 J	PRINCETON J N	40	286	306	4	17	4	12
53	15209 J	PITTSBURGH J	40	281	365	5	18	3	14
54	15228 J	BUFFALO J NY	42	282	272	0	17	1	20
55	15230 J	PORTLAND ME.	43	290	225	0	13	0	14
56	15236 J	SYRACUSE	43	284	262	0	14	1	16
57	15303 J	COLUMBUS OH	40	277	378	4	19	3	15
58	15317 M	CHICAGO M IL	41	273	301	1	20	1	29
59	15323 J	DETROIT	42	277	289	1	18	1	25
60	15339 J	MADISON J WI	43	271	277	0	18	0	40
61	15414 J	STUART	41	266	332	2	19	1	25
62	15416 J	FREMONT	41	264	342	2	20	2	24
63	15426 J	SIOUX CITY J	42	264	308	1	18	1	18
64	15436 J	SIOUX FALLS J	43	264	292	0	17	0	18
65	15443 L	MINNEAPOLIS L	44	267	226	0	14	0	24
66	15514 M	CHEYENNE M WY	41	256	554	25	17	10	6
67	15526 L	CASPER L WY	42	254	438	9	19	4	11
68	15543 J	RAPID CITY J	44	257	345	1	16	1	13
69	15546 J	SHERIDAN J WY	44	254	330	1	20	1	15
70	15558 M	BILLINGS M MT	45	252	294	0	17	0	16
71	15560 K	BISMARCK K ND	46	260	336	0	7	0	10
72	15601 K	SALT LAKE CIT	40	249	498	15	25	6	8
73	15636 J	BOISE J ID	43	244	334	1	28	1	13
74	15671 L	GREAT FALLS L	47	249	238	0	16	0	18
75	15682 B	CUTBANK B	48	248	215	1	15	0	18
76	15752 J	PORTLAND J OR	45	238	206	1	21	0	17
77	15772 P	SEATTLE P WA	47	238	185	2	13	0	18

absolute measurements do not improve the whole net much and the improvements are more local than at the beginning. Another interpretation could be that the correlation is getting smaller and accuracies of measured gravity differences between stations are not good enough to transfer information from new absolute measurements very far through the net. If we leave out 5 stations in the net, which have the variances above 1000 μgal then the average variance after two selections is 259 μgal^2 or σ = 16 μgal, and after four selections 237 μgal^2 or σ = 15 μgal. The gained accuracy from two additional absolute measurements would not be significant.

4.7 Conclusions

The original scope of the study was to determine the preferred locations for new absolute measurements to improve IGSN 71 global net. This was accomplished in the early part of the contract as reported in Chapter 6, section 6.1. Six stations were suggested as the preferred sites for new absolute measurements. It was noted that the last two new measurements made contributions more to the local area than to the global net. During the work new absolute measurements were made at ten more sites in Europe. A new selection of the preferred sites was made by including these new absolute measurements in Europe to the IGSN 71 net. The original variance-covariance matrix of IGSN 71 was obtained by single precision computations; therefore, no more than six new sites were obtained. It is our opinion that we started to loose significant figures to that extent that the seventh selection could have been effected too much by rounding off noise.

We repeated the above mentioned selection processes using the UAU-net, which included also second order correction terms to the calibrations of the gravimeters. The second order effect is

clearly seen from the preferred selections as compared to the selections obtained from IGSN 71 net.

From these studies it became clear that the strong correlations between gravity values in the nets were disappearing and the existing gravity ties with their current accuracies could not transfer the effect of new absolute measurements far in the global nets. Therefore, in the future, there should be new absolute measurements of gravity on different continents and local areas. We should not try to make new global adjustments of networks but rather continental or national network adjustments including new absolute measurements in the area in question.

We had not planned originally to do separate analyses for Africa or North America and the United States. However, we made extensive study in the areas, especially in North America and the United States. The results were given in Chapter 6, section 6.3. The comments were given in the same section. If we wish to improve the U.S. Network, we must do more accurate measurements of gravity differences between the stations or we have to make a very large number of absolute measurements of gravity. In order to improve accuracies of relative gravity measurements we must establish a good calibration line for gravimeters and possibly improve measuring techniques and analyze environmental effects more precisely than before.

5. Analyses on the location of absolute gravity measurements for calibration of gravimeters

5.1 Introduction

During the adjustment of IGSN 71 net it was recognized that the second order correction term to the calibrations of gravimeters

would be appropriate. The mathematical model for inclusion of this second order term was worked out and used in an adjustment of IGSN 71 net (Uotila, 1974). It was found that the distribution of absolute sites in IGSN 71 was not good for solving the second order term. The task under this contract was to determine proper intervals for additional absolute sites in order to solve the second and higher order terms for calibration of gravimeters.

5.2 Mathematical model

A proper mathematical model for the inclusion of second or higher order correction terms to the calibration of gravimeters, must include the dial readings because the higher order terms are affected by the location of the readings in the total range of readings.

A possible mathematical model for two dial readings with a gravimeter in a trip including the third order correction term is:

$$d_i^a - d_j^a + k^a (t_i - t_j) + \ell^a (d_i^a - d_j^a) + m^a ({d_i^a}^2 - {d_j^a}^2) + n^a ({d_i^a}^3 - {d_j^a}^3) - (g_i^a - g_j^a) = 0$$

where

d_i, d_j = dial readings in mgal at the stations i and j, respectively, corrected for all known systematic effects.

k = coefficient for drift.

t_i, t_j = time of observation of the dial readings at station i and j, respectively.

ℓ = coefficient for a linear scale factor term.

m = coefficient for a second order scale factor term.

n = coefficient for a third order scale factor term.

g_i, g_j = gravity values in mgal at the stations i and j, respectively.

a = superscript indicating theoretical or adjusted value.

We would have a similar equation for each gravity difference. The general form of this mathematical model is

$$F(X^a, L^a) = 0$$

where X^a = theoretical or adjusted values of parameters

L^a = theoretical or adjusted values of quantities that have been observed or to be observed.

In this case X^a would include k^a, ℓ^a, m^a and n^a for each instrument for the time periods during which they are considered invariant, and g_i^a for each station included in the net. The vector L^a would have each dial reading of the instrument as an element. The values t_i and t_j are considered errorless in this model. The model can be, of course, expanded to include even higher order correction terms to the calibration of the gravimeters.

The usual minimum variance solution for the above model is:

$$X = -[A^T(BP^{-1}B^T)^{-1}A]^{-1} A^T(BP^{-1}B^T)^{-1} W$$

where

$$A = \left.\frac{\partial F}{\partial X^a}\right|_{X^a=X^0} ; \quad B = \left.\frac{\partial F}{\partial L^a}\right|_{L^a=L^b} ; \quad W = F(L^b, X^0)$$

$P^{-1} = \Sigma_{L_b}$ = variance-covariance matrix of observed quantities,

L^b = values of observed quantities,

X^0 = approximate values of parameters,

$X^a = X^0 + X$ = adjusted values of parameters.

The variance-covariance matrix of the parameters has the form:

$$\Sigma_{X^a} = [A^T(BP^{-1}B^T)^{-1}A]^{-1}:$$

For each absolute gravity measurement we would have a mathematical model:

$$c_i^a - g_i^a = 0$$

where c_i^a is the adjusted value of the absolute gravity measurement at i^{th} station and g_i^a is the adjusted gravity value of the i^{th} station. The absolute values can be added to the earlier expression:

$$X = -[A^T(BP^{-1}B^T)^{-1} A+P_x]^{-1} [A^T(BP^{-1}B^T)^{-1} W-P_x W_c]$$

where dimensions of P_x are the same as $A^T(BP^{-1}B^T)^{-1}A$ or u x u when the dimensions of X are u x 1. All other elements of P_x are zero except those diagonal elements, which correpond to corrections to the g values where absolute measurements have been made. The non-zero diagonal element, $p_{x_{ii}}$, is equal to $\frac{1}{\sigma_{x_i}^2}$ which is the reciprocal of the variance of the absolute measurement at the i^{th} station. The corresponding w_c element is

$$w_{c_i} = c_i^b - g_i^0$$

where c_i^b is the measured absolute value at the i^{th} station and g_i^0 is the approximate gravity value at the i^{th} station adopted for the solution. All other elements of W_c-matrix are zero except those corresponding to the sites where absolute measurements have been made. The corresponding variance-covariance matrix of parameters is:

$$\Sigma_{X^a} = [A^T(BP^{-1}B^T)^{-1} A + P_x]^{-1}$$

If the higher order drift terms or some environmental factors, such as temperature and pressure were to be included in the model, they could be easily added by modifying the mathematical model correspondingly.

5.3 Results of analyses

5.3.1 Linear correction term

If we were interested in solving only the linear correction term to the calibration of a gravimeter, then with current accuracies of absolute

gravity measurements, 10-20 μgal, it would be satisfactory to have only two absolute measurements, located at the stations having the minimum and maximum gravity values of the calibration line. The additional information obtained by including more absolute measurements between these points would not increase the accuracy of determination of the linear calibration correction term as much as making these additional measurements at these points equally divided between the two points of the calibration line.

5.3.2 Linear and the second order correction term

In the case that we wish to determine the linear and the second order correction terms to the calibration of the gravimeters the analyses showed that we should have absolute measurements at the following locations along the calibration line: at the station having maximum gravity value and at the station having minimum gravity value and the third one at the station having close to the average of minimum and maximum gravity values along the calibration line. Several alternative situations were examined, but this simple system seemed to give the best results for the case. The additional information obtained by including more absolute measurements between these points would not increase the accuracy of the determination of the correction terms to gravimeters as much as making these new measurements at these three points or at the vicinity of these three points.

5.3.3 Higher order correction terms

We had available the factory calibration tables for 26 La Coste-Romberg G gravimeters. The curves of the original calibrations were plotted for the full operational scale of the gravimeters. In table 12 we see the results of the fits of 2nd, 3rd,

4th and 5th order polynomials to the calibration curves. Figures 3-12 give some sample residuals of the polynomial fits of typical calibration curves. It should be noted that the scale in the vertical axis is not the same in all figures. The percentages accounted by the polynomials are given in table 12. The percentage accounted for is computed using the following formula

$$\text{Percentage accounted for} = \frac{\Sigma x_i^2 - \Sigma v_i^2}{\Sigma x_i^2} \times 100$$

where x_i = residuals after a first order polynomial fit.

v_i = residuals after a particular polynomial fit.

Similar analyses were made for the calibration curves for the measuring interval which has been used in IGSN 71 net and for the interval used in the U.S.A. The corresponding graphs of residuals were also plotted for these polynomials, but in much larger scale. Examples are given for two gravimeters, namely L045 and L803 in Figures 13-16. We should again note differences in scale from figure to figure. We tried to do also some spectral analyses, but did not find them helpful in these evaluations at this time.

Based solely on the examination of the factory calibration curves we can conclude that the curves can be reproduced to the operational accuracy of La Coste-Romberg G gravimeters by making absolute measurements at 500 mgal intervals. It is known that these gravimeters have been calibrated in the factory using 200 mgal rider at various parts of the meter's range (Harrison and La Coste, 1978). This 200 mgal interval does not seem to show up in the calibration curves. It is clear, of course, that if absolute measurements are made at 200 mgal interval along a calibration line, we should be able to control calibration of the gravimeters to the same accuracy as the factory calibration does; however, we must take into consideration changes in local environmental conditions, such as the effects of tidal variations, changes in water level, etc.

Table 12

Analyses of LaCoste-Romberg-factory calibration curves

Gravimeter #	Trend Removed-Percent Accounted Order of Polynomial 2nd	3rd	4th	5th
L 001	26.6	88.9	99.16	99.36
L 002	84.9	91.7	97.31	99.56
L 007	39.7	92.0	99.81	99.85
L 009	52.4	97.5	99.95	99.95
L 011	15.7	83.9	99.74	99.75
L 012	2.5	94.9	99.93	99.94
L 020	83.8	96.2	99.97	99.98
L 043	94.5	97.8	99.91	99.91
L 044	84.9	92.5	99.72	99.80
L 045	19.7	90.7	95.08	96.74
L 046	47.1	94.1	99.37	99.43
L 047	16.4	60.4	99.58	99.82
L 048	85.6	89.3	99.78	99.97
L 050	91.9	92.0	99.71	99.94
L 056	28.2	64.1	99.00	99.69
L 057	79.7	94.7	99.70	99.90
L 074	65.2	90.2	99.94	99.95
L 075	87.2	90.2	99.87	99.87
L 093	86.4	98.6	99.99	99.99
L 115	63.0	88.7	99.94	99.99
L 122	85.4	96.0	99.98	99.98
L 137	0.6	69.3	99.29	99.70
L 140	91.8	96.9	99.89	99.98
L 803	97.8	98.2	99.34	99.45
L 808	62.0	91.3	99.77	99.99
L 903	93.7	95.0	99.58	99.62

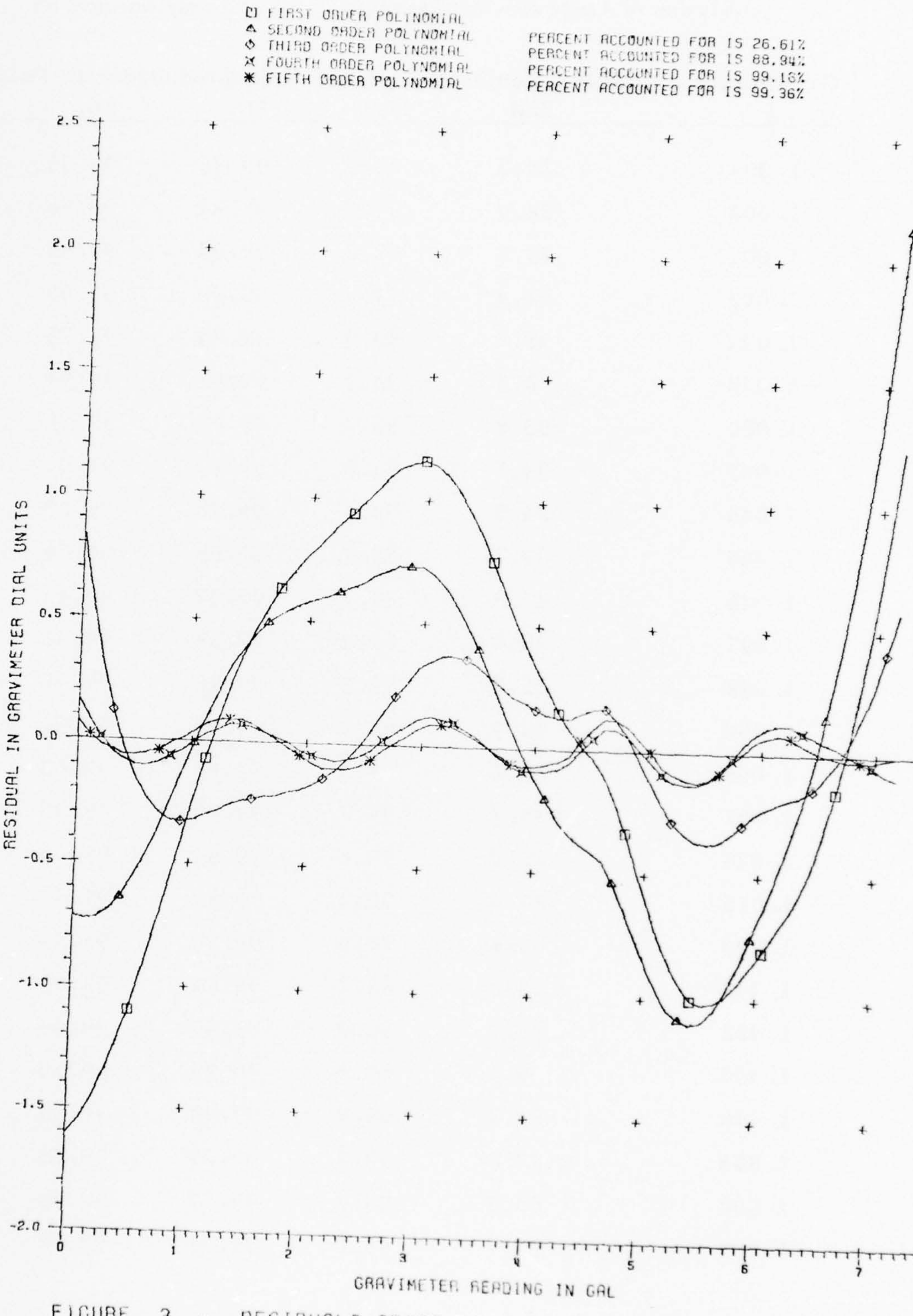

FIGURE 3 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L001

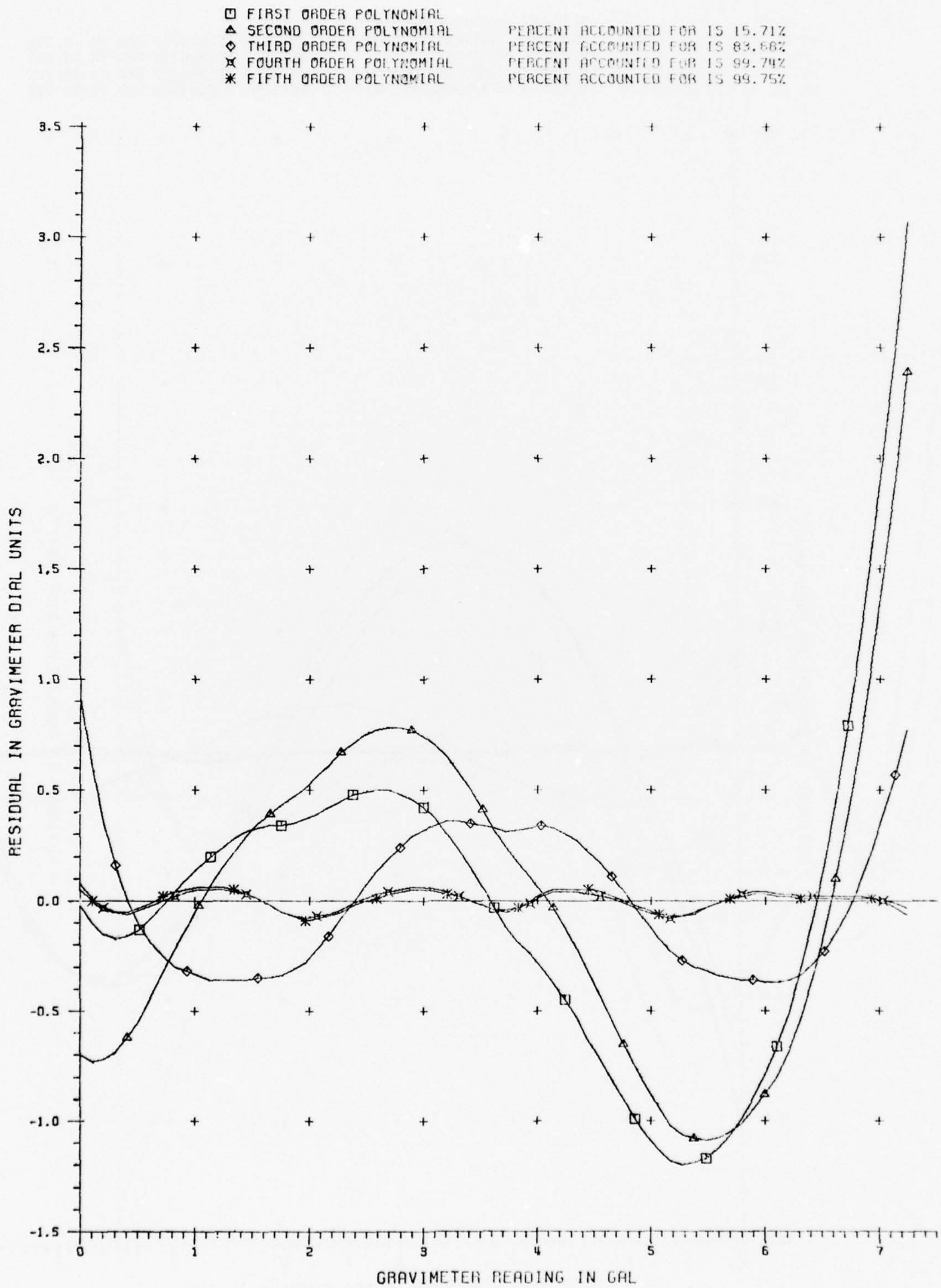

FIGURE 4 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L011

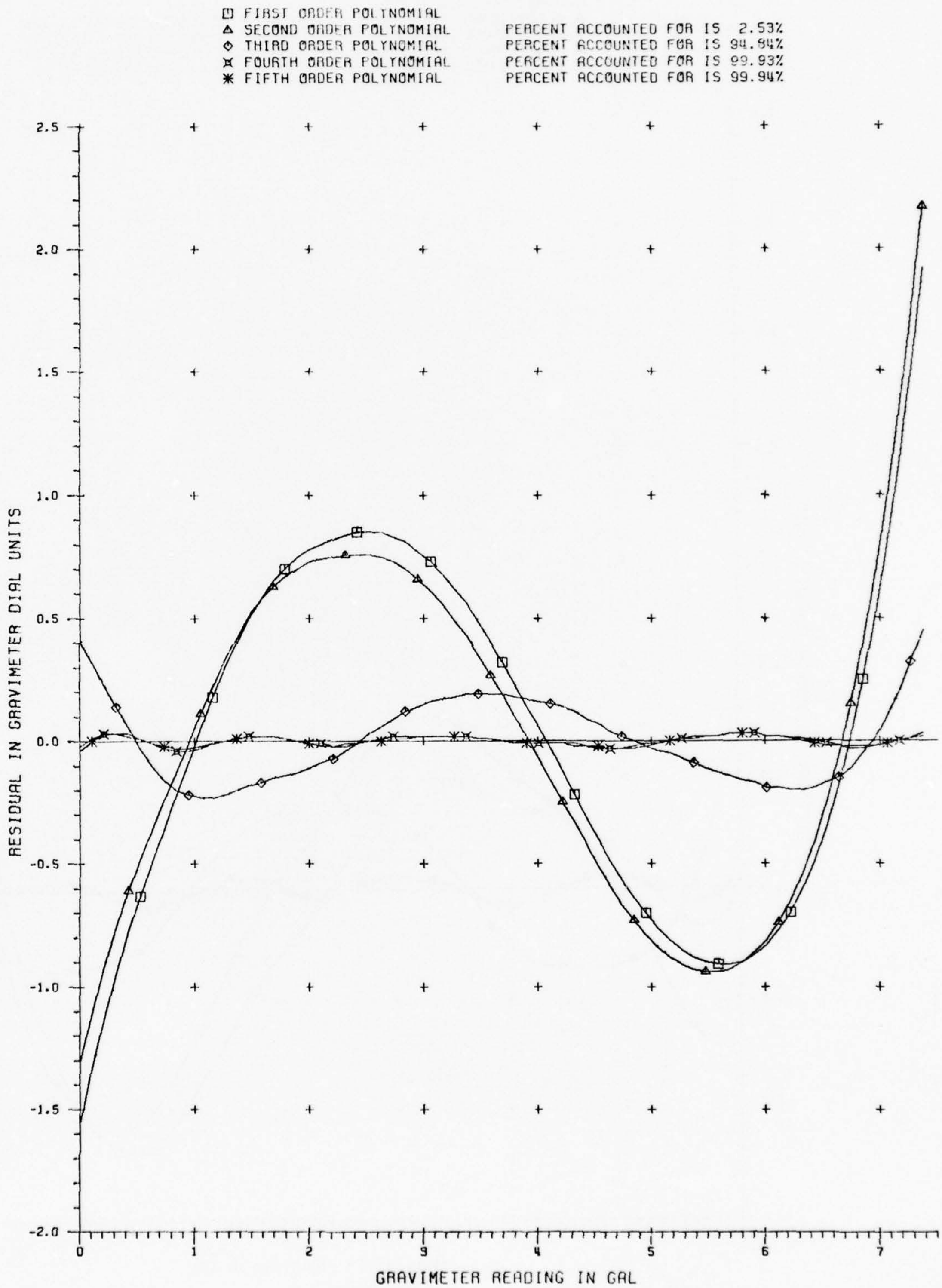

FIGURE 5 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L012

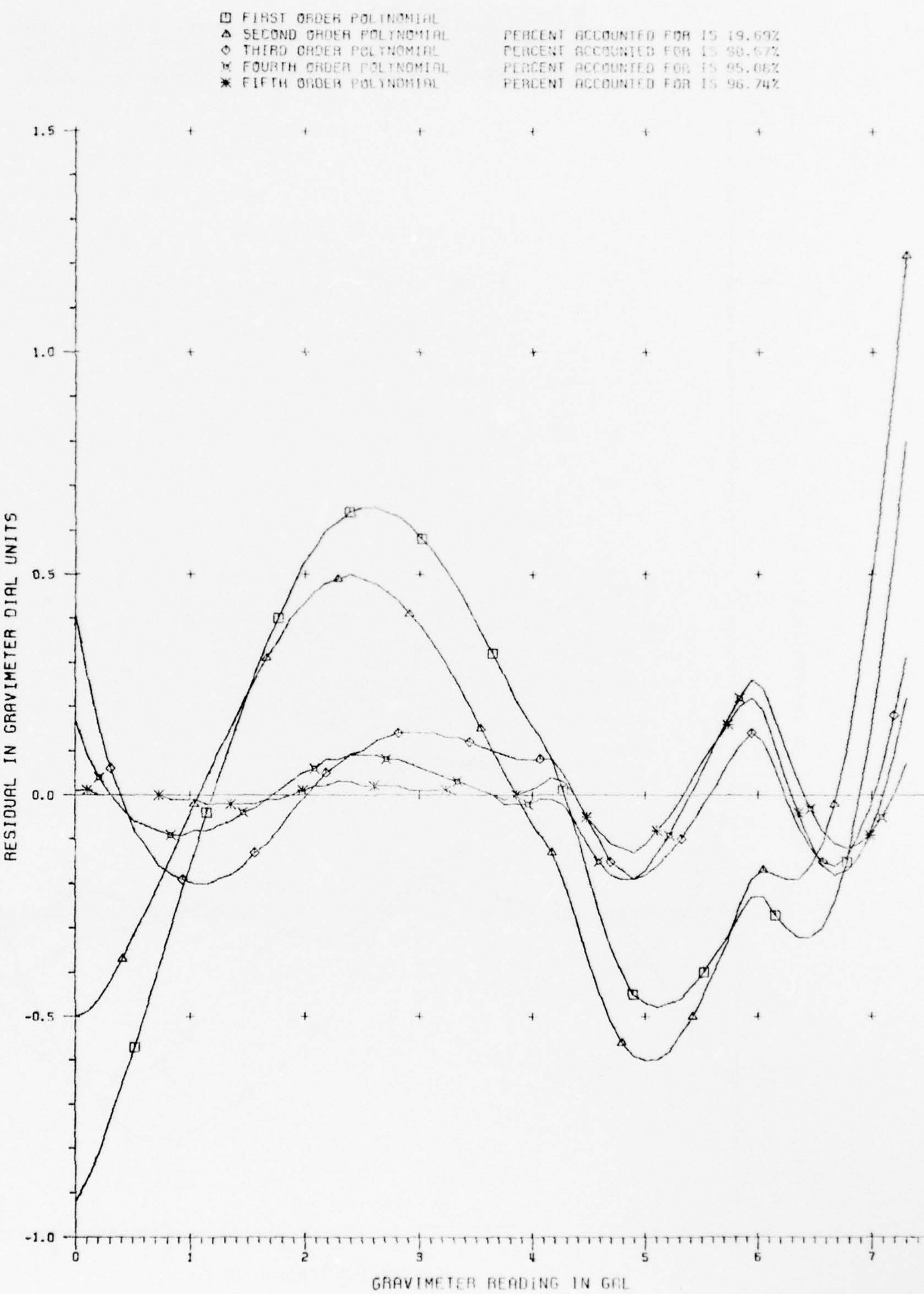

FIGURE 6 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L045

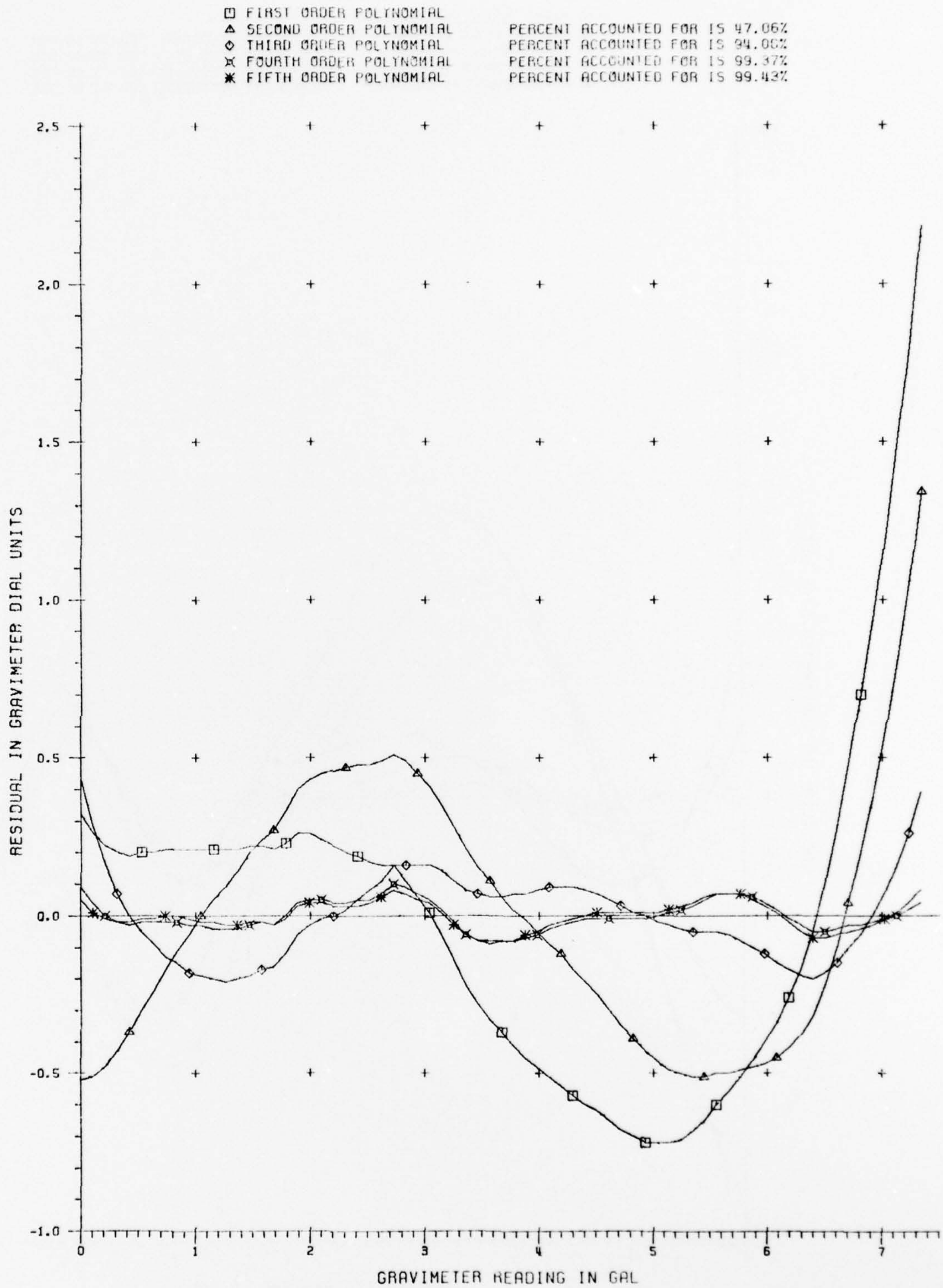

FIGURE 7 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L046

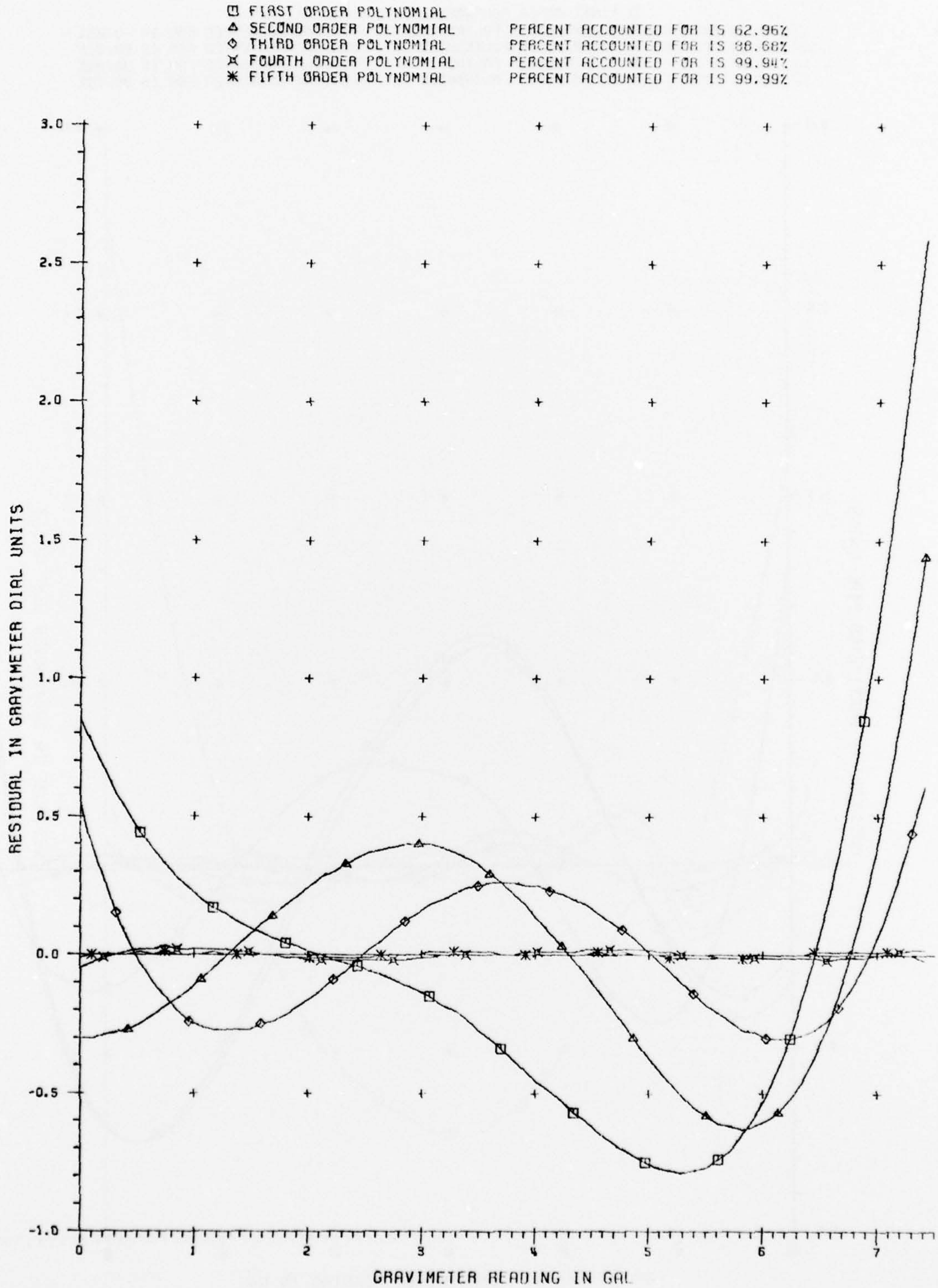

FIGURE 8 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L115

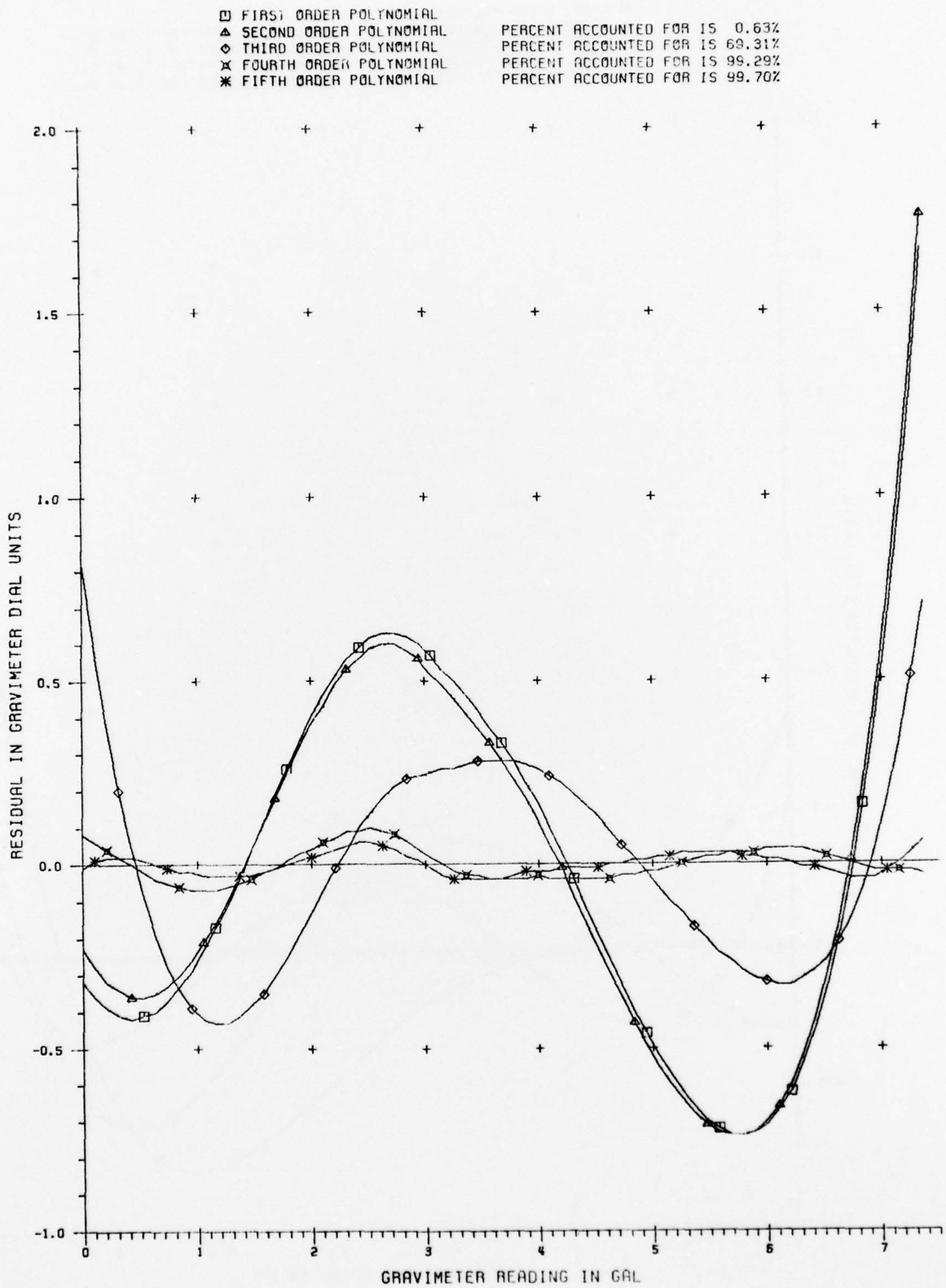

FIGURE 9 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L137

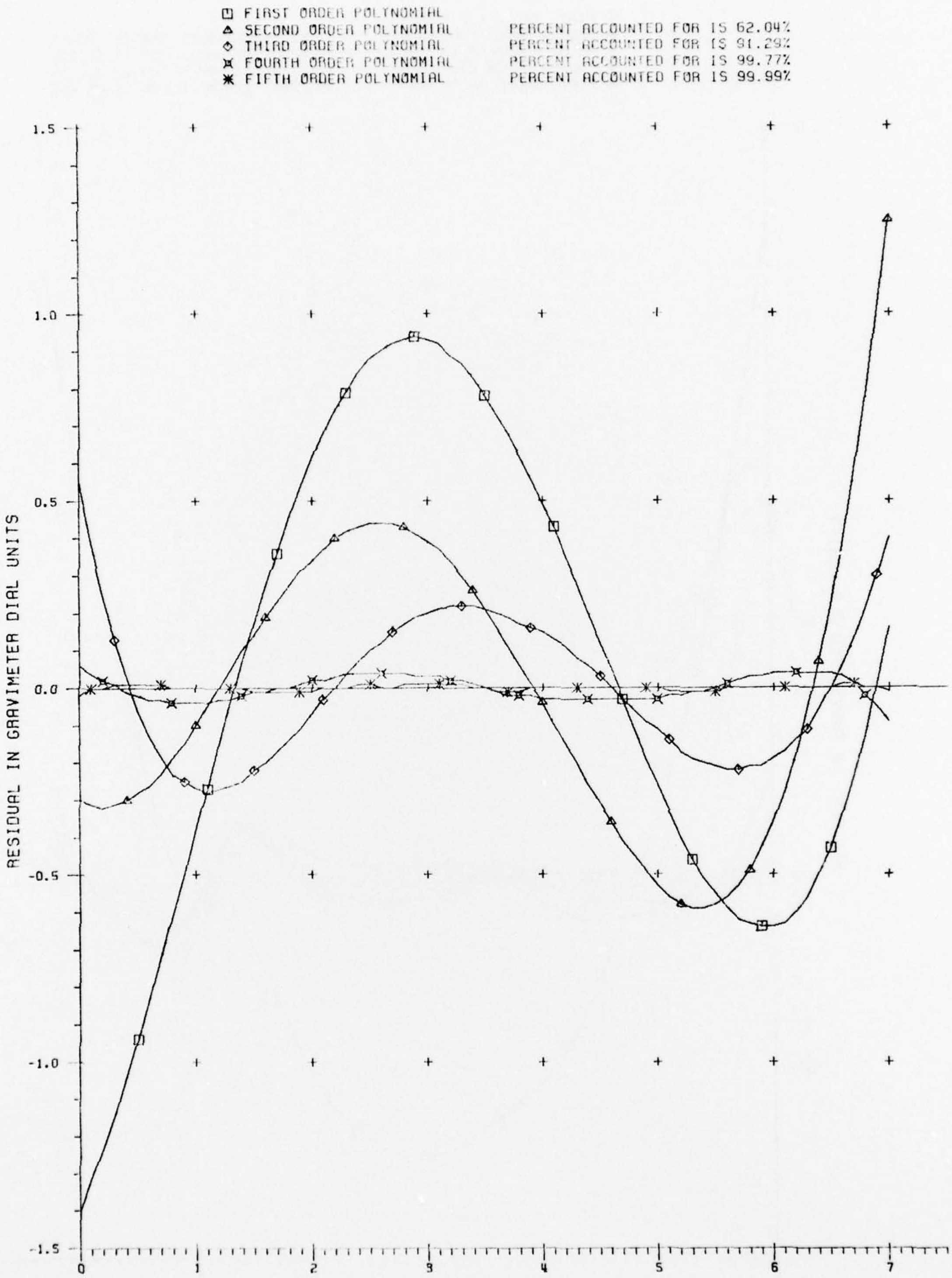

FIGURE 11 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L808

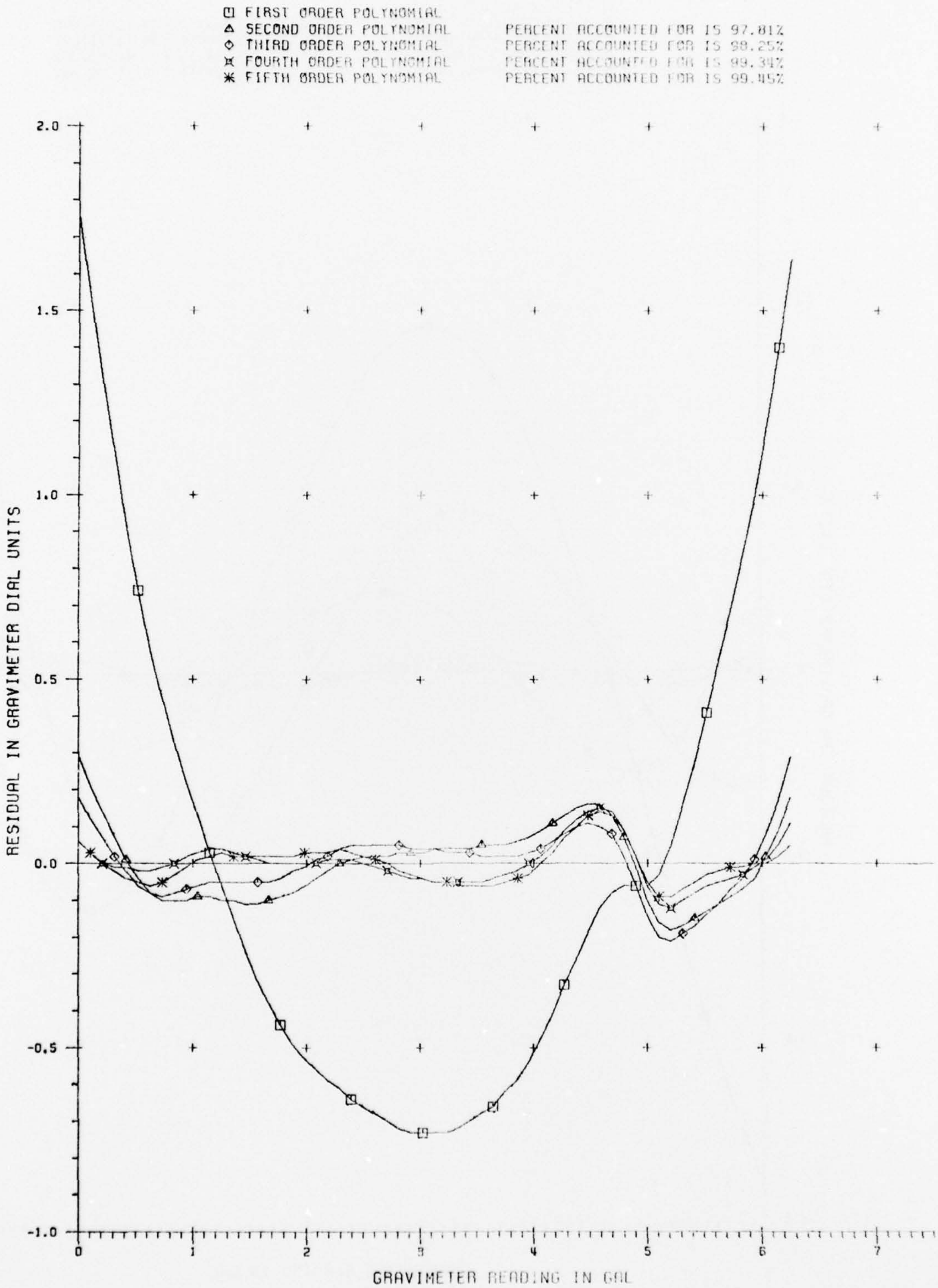

FIGURE 10 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L803

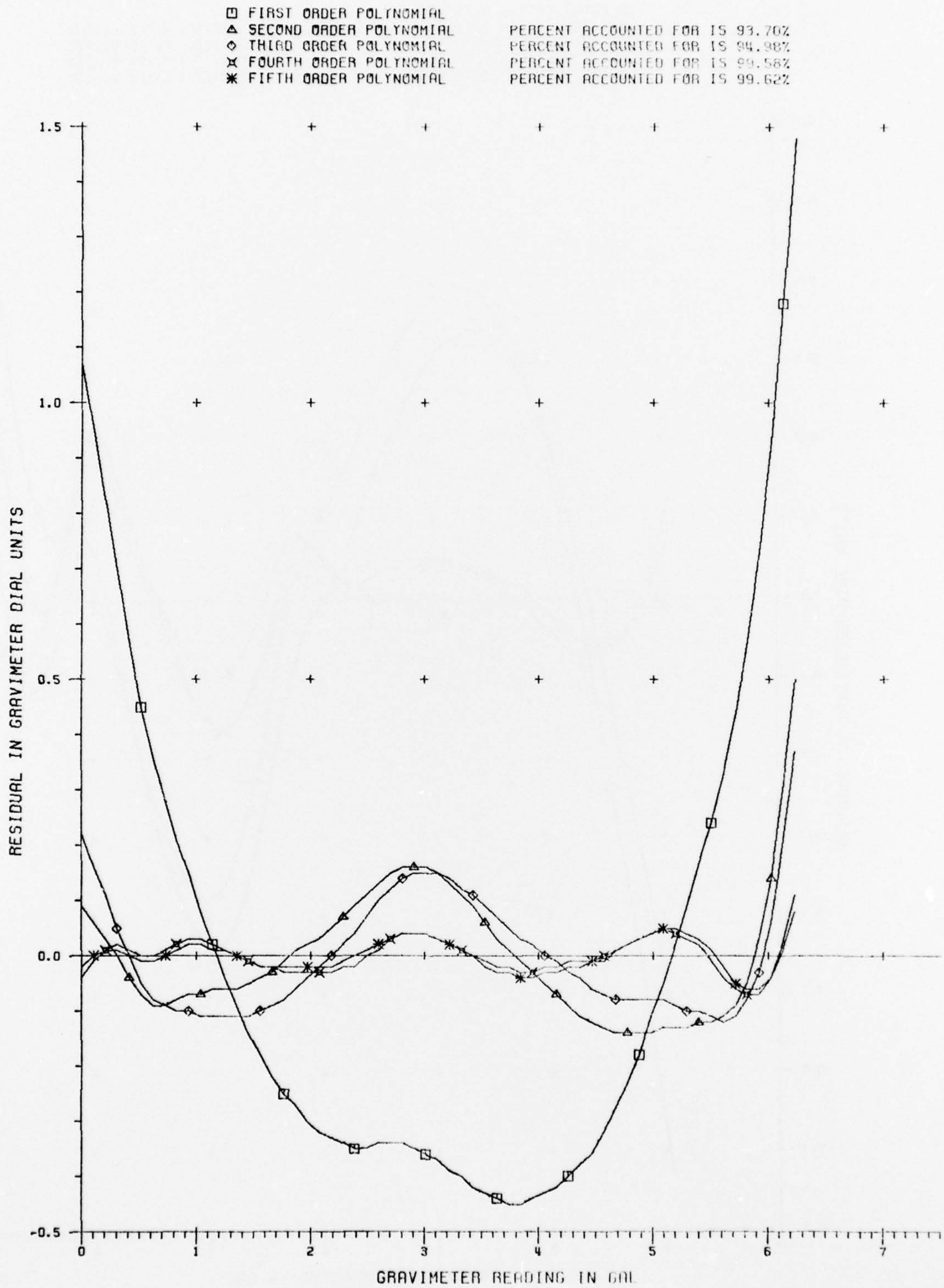

FIGURE 12 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L903

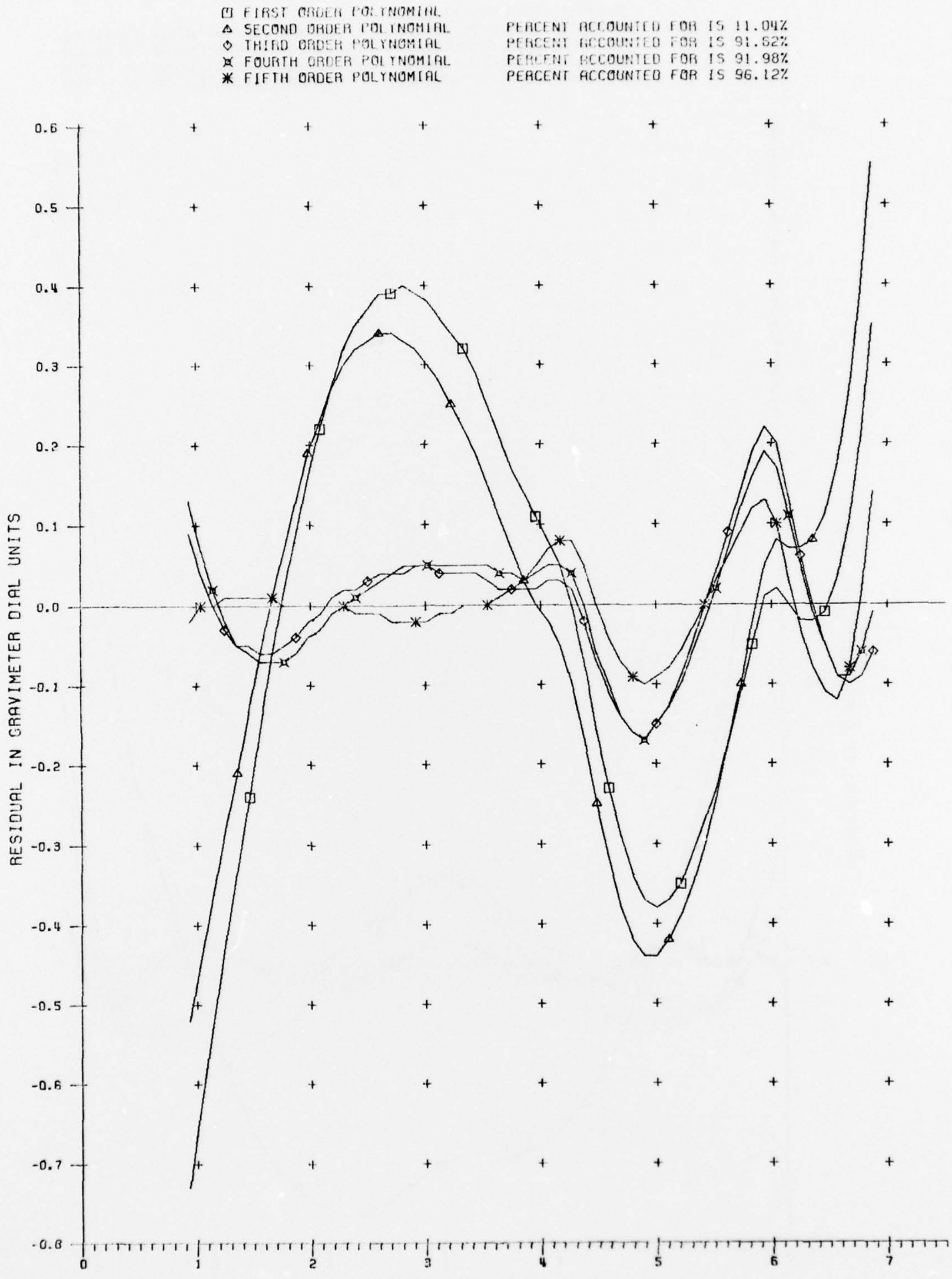

FIGURE 13 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L045

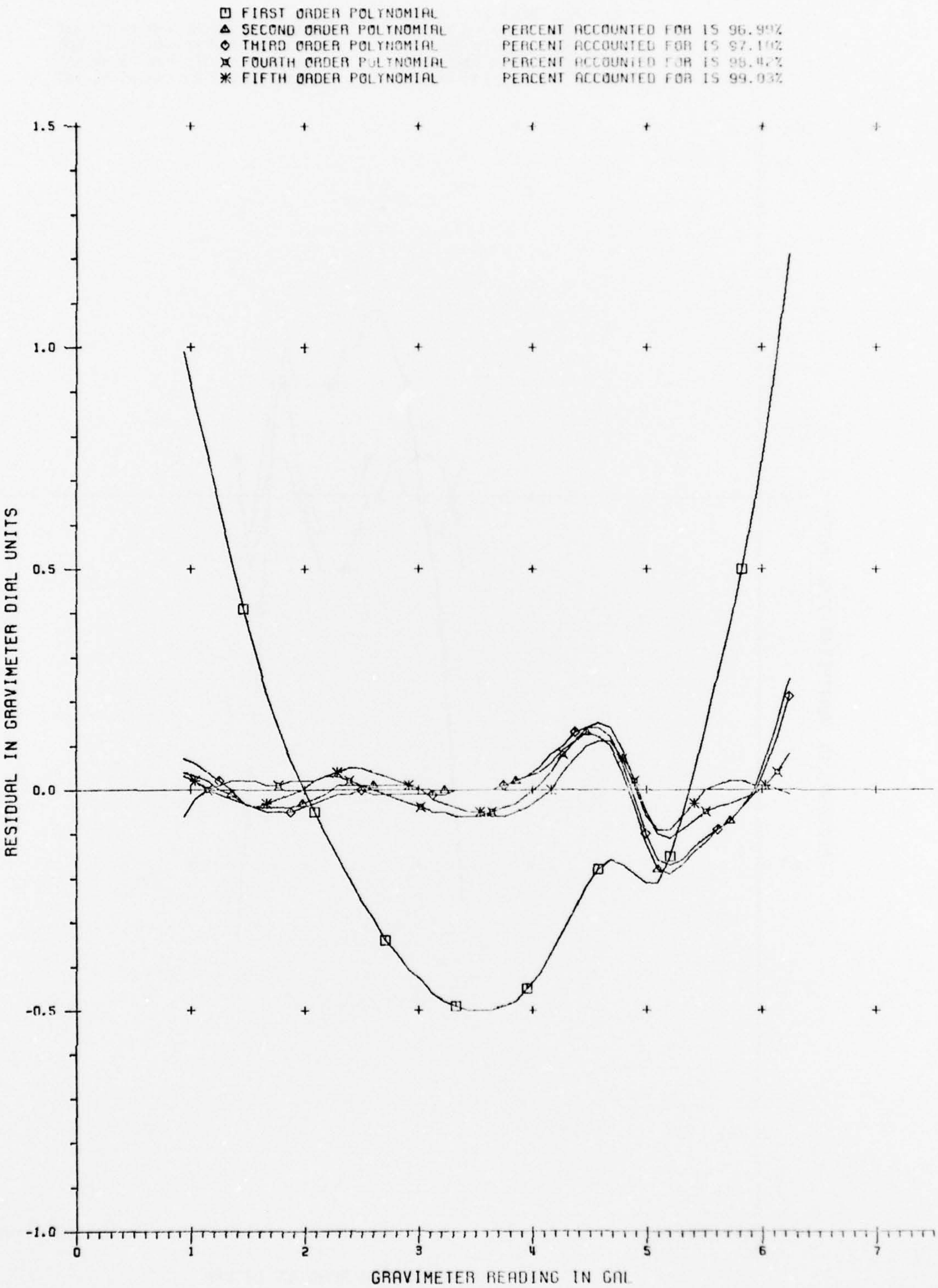

FIGURE 14 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L803

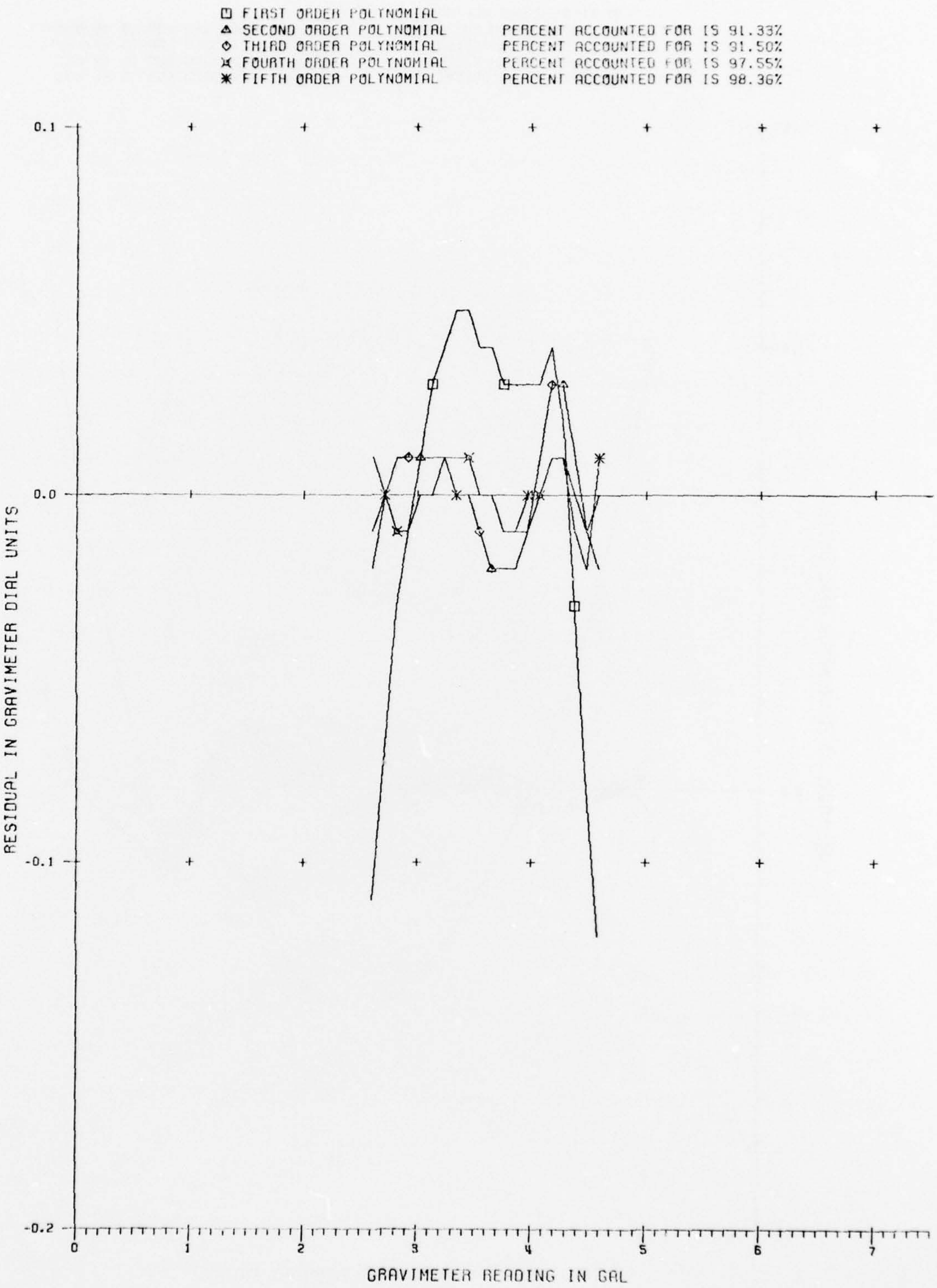

FIGURE 15 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L045

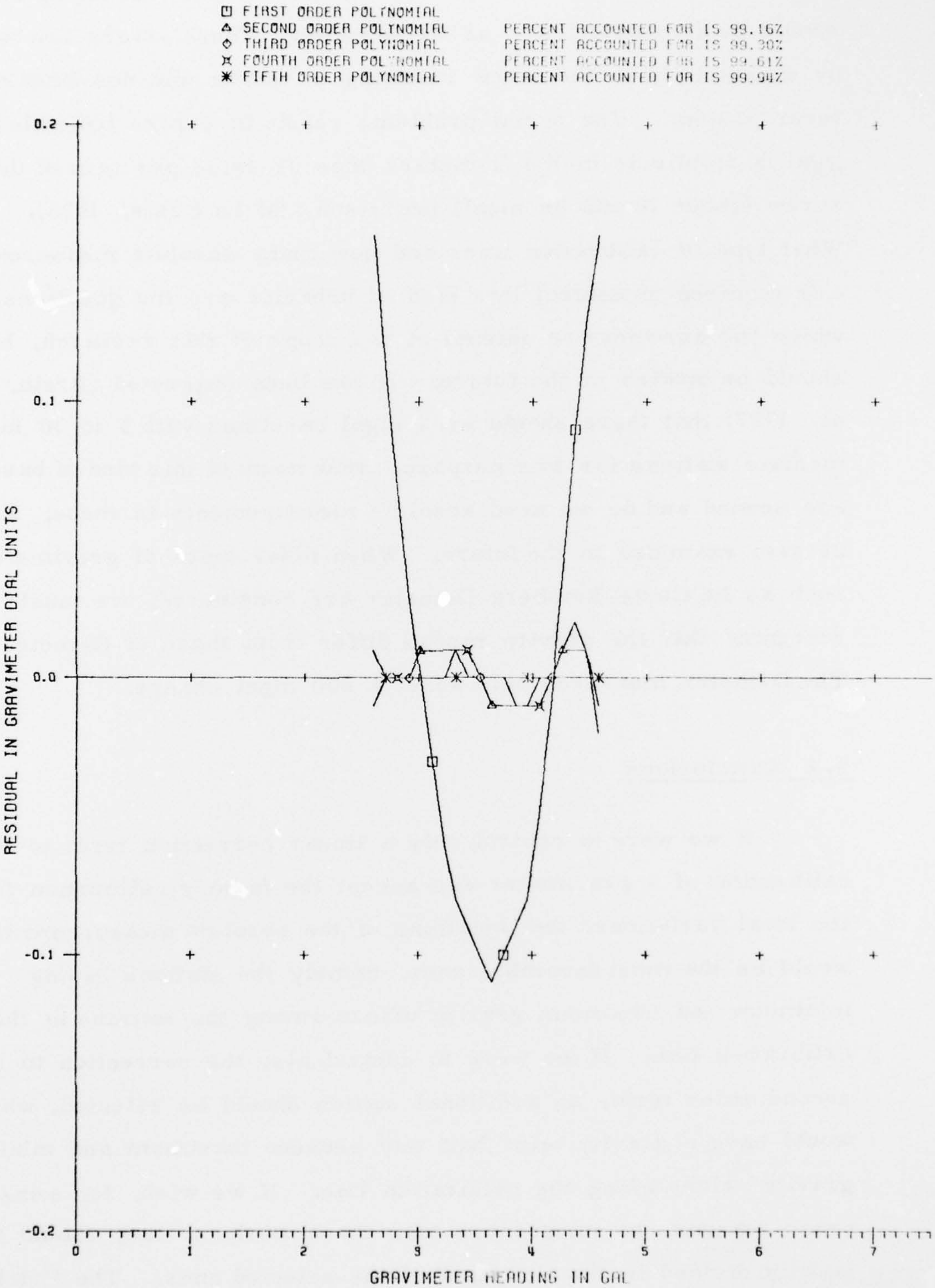

FIGURE 16 - RESIDUALS AFTER POLYNOMIAL FIT FOR INSTRUMENT L803

(Brein, et al, 1977). The periodic errors in the measuring screw should be also modeled if at all possible. These errors are caused by excentricity in the screw resulting in wobble and non-linearity of lever system. The screw problems result in errors typically 35 μgal in amplitude in the G-meters once or twice per turn of the screw (about 70 and 35 mgal) (Harrison and La Coste, 1978). What type of calibration lines and how many absolute measurements are required to control this kind of behavior are the questions, for which the answers are outside of the scope of this research, but should be studied in the future. It has been suggested (Brein, et al, 1977) that there should be 1 mgal baselines with 5 to 10 intermediate stations for this purpose. How many of this kind of baselines are needed and do we need absolute measurements in these, should be also examined in the future. When other types of gravimeters such as La Coste-Romberg D-meter are considered, we must recognize that the gravity ranges differ from those of G-meter. The D-meter measures only about a 200 mgal change.

5.4 Conclusions

If we were to control only a linear correction term to the calibration of a gravimeter and accept the factory calibration for the local variations, two locations of the absolute measurements would be the most favorable ones, namely the stations having minimum and maximum gravity values among the stations in the calibration line. If we were to control also the correction to the second order term, an additional station should be selected, which would have a gravity value half way between maximum and minimum gravity values along the calibration line. If we wish, for some other reasons, to select more than these stations, they should be equally divided in the vicinities of the selected ones. The "vicinity"

means in this context - having close to the same gravity values.

If we wish to reproduce similar calibration curve as the one supplied by the factory for G-meters, 500 mgal interval is satisfactory provided that environmental effects are taken into consideration. If we wish to obtain 10 μgal or better accuracy in measurements of gravity differences, we must establish calibration lines of smaller gravity differences related to the gravity differences to be measured. For accurate measurements and field calibrations continuous recording of tidal and other variations of gravity should be made at the stations for correcting values to the normal values.

6. References

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7. List of scientific personnel

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